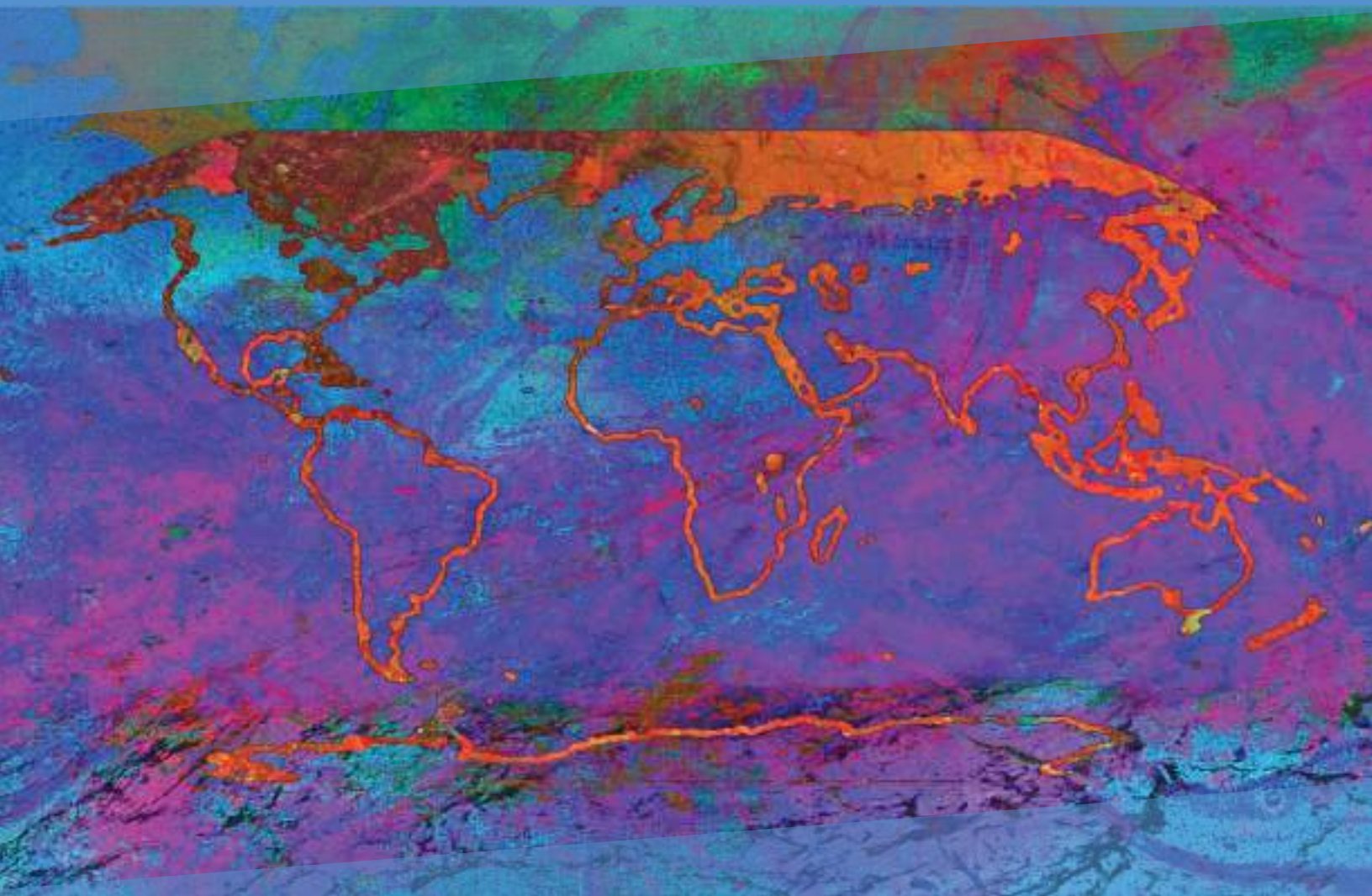


Climate Change 2021

The Physical Science Basis

Summary for Policymakers



WGI

Working Group I Contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change



Climate Change 2021

The Physical Science Basis

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Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group I (WGI) contribution to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6)¹ on the physical science basis of climate change. The report builds upon the 2013 Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) and the 2018–2019 IPCC Special Reports² of the AR6 cycle and incorporates subsequent new evidence from climate science.³

This SPM provides a high-level summary of the understanding of the current state of the climate, including how it is changing and the role of human influence, the state of knowledge about possible climate futures, climate information relevant to regions and sectors, and limiting human-induced climate change.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence indicated using the IPCC calibrated language.⁴

The scientific basis for each key finding is found in chapter sections of the main Report and in the integrated synthesis presented in the Technical Summary (hereafter TS), and is indicated in curly brackets. The AR6 WGI Interactive Atlas facilitates exploration of these key synthesis findings, and supporting climate change information, across the WGI reference regions.⁵

A. The Current State of the Climate

Since AR5, improvements in observationally based estimates and information from paleoclimate archives provide a comprehensive view of each component of the climate system and its changes to date. New climate model simulations, new analyses, and methods combining multiple lines of evidence lead to improved understanding of human influence on a wider range of climate variables, including weather and climate extremes. The time periods considered throughout this section depend upon the availability of observational products, paleoclimate archives and peer-reviewed studies.

A.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.
{2.2, 2.3, Cross-Chapter Box 2.3, 3.3, 3.4, 3.5, 3.6, 3.8, 5.2, 5.3, 6.4, 7.3, 8.3, 9.2, 9.3, 9.5, 9.6, Cross-Chapter Box 9.1} (Figure SPM.1, Figure SPM.2)

A.1.1 Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR5), concentrations have continued to increase in the atmosphere, reaching annual averages of 410 parts per million (ppm) for carbon dioxide (CO₂), 1866 parts per billion (ppb) for methane (CH₄), and 332 ppb for nitrous oxide (N₂O) in 2019.⁶ Land and ocean have taken up a near-constant proportion (globally about 56% per year) of CO₂ emissions from human activities over the past six decades, with regional differences (*high confidence*).⁷
{2.2, 5.2, 7.3, TS.2.2, Box TS.5}

1 Decision IPCC/CLVI-2.

2 The three Special Reports are: Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

3 The assessment covers scientific literature accepted for publication by 31 January 2021.

4 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in *italics*, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or result: virtually certain 99–100% probability; very likely 90–100%; likely 66–100%; about as likely as not 33–66%; unlikely 0–33%; very unlikely 0–10%; and exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%; more likely than not >50–100%; and extremely unlikely 0–5%) are also used when appropriate. Assessed likelihood is typeset in *italics*, for example, *very likely*. This is consistent with AR5. In this Report, unless stated otherwise, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

5 The Interactive Atlas is available at <https://interactive-atlas.ipcc.ch>

6 Other GHG concentrations in 2019 were: perfluorocarbons (PFCs) – 109 parts per trillion (ppt) CF₄ equivalent; sulphur hexafluoride (SF₆) – 10 ppt; nitrogen trifluoride (NF₃) – 2 ppt; hydrofluorocarbons (HFCs) – 237 ppt HFC-134a equivalent; other Montreal Protocol gases (mainly chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)) – 1032 ppt CFC-12 equivalent). Increases from 2011 are 19 ppm for CO₂, 63 ppb for CH₄ and 8 ppb for N₂O.

7 Land and ocean are not substantial sinks for other GHGs.

- A.1.2 Each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature⁸ in the first two decades of the 21st century (2001–2020) was 0.99 [0.84 to 1.10] °C higher than 1850–1900.⁹ Global surface temperature was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C). The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22] °C). Additionally, methodological advances and new datasets contributed approximately 0.1°C to the updated estimate of warming in AR6.¹⁰ {2.3, Cross-Chapter Box 2.3} (Figure SPM.1)
- A.1.3 The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019¹¹ is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that well-mixed GHGs were the main driver¹² of tropospheric warming since 1979 and *extremely likely* that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s. {3.3, 6.4, 7.3, TS.2.3, Cross-Section Box TS.1} (Figure SPM.2)
- A.1.4 Globally averaged precipitation over land has *likely* increased since 1950, with a faster rate of increase since the 1980s (*medium confidence*). It is *likely* that human influence contributed to the pattern of observed precipitation changes since the mid-20th century and *extremely likely* that human influence contributed to the pattern of observed changes in near-surface ocean salinity. Mid-latitude storm tracks have *likely* shifted poleward in both hemispheres since the 1980s, with marked seasonality in trends (*medium confidence*). For the Southern Hemisphere, human influence *very likely* contributed to the poleward shift of the closely related extratropical jet in austral summer. {2.3, 3.3, 8.3, 9.2, TS.2.3, TS.2.4, Box TS.6}
- A.1.5 Human influence is *very likely* the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019 (decreases of about 40% in September and about 10% in March). There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large internal variability. Human influence *very likely* contributed to the decrease in Northern Hemisphere spring snow cover since 1950. It is *very likely* that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades, but there is only *limited evidence*, with *medium agreement*, of human influence on the Antarctic Ice Sheet mass loss. {2.3, 3.4, 8.3, 9.3, 9.5, TS.2.5}
- A.1.6 It is *virtually certain* that the global upper ocean (0–700 m) has warmed since the 1970s and *extremely likely* that human influence is the main driver. It is *virtually certain* that human-caused CO₂ emissions are the main driver of current global acidification of the surface open ocean. There is *high confidence* that oxygen levels have dropped in many upper ocean regions since the mid-20th century and *medium confidence* that human influence contributed to this drop. {2.3, 3.5, 3.6, 5.3, 9.2, TS.2.4}
- A.1.7 Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr^{–1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr^{–1} between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr^{–1} between 2006 and 2018 (*high confidence*). Human influence was *very likely* the main driver of these increases since at least 1971. {2.3, 3.5, 9.6, Cross-Chapter Box 9.1, Box TS.4}

8 The term ‘global surface temperature’ is used in reference to both global mean surface temperature and global surface air temperature throughout this SPM. Changes in these quantities are assessed with *high confidence* to differ by at most 10% from one another, but conflicting lines of evidence lead to *low confidence* in the sign (direction) of any difference in long-term trend. {Cross-Section Box TS.1}

9 The period 1850–1900 represents the earliest period of sufficiently globally complete observations to estimate global surface temperature and, consistent with AR5 and SR1.5, is used as an approximation for pre-industrial conditions.

10 Since AR5, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

11 The period distinction with A.1.2 arises because the attribution studies consider this slightly earlier period. The observed warming to 2010–2019 is 1.06 [0.88 to 1.21] °C.

12 Throughout this SPM, ‘main driver’ means responsible for more than 50% of the change.

- A.1.8 Changes in the land biosphere since 1970 are consistent with global warming: climate zones have shifted poleward in both hemispheres, and the growing season has on average lengthened by up to two days per decade since the 1950s in the Northern Hemisphere extratropics (*high confidence*).
{2.3, TS.2.6}

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850–1900

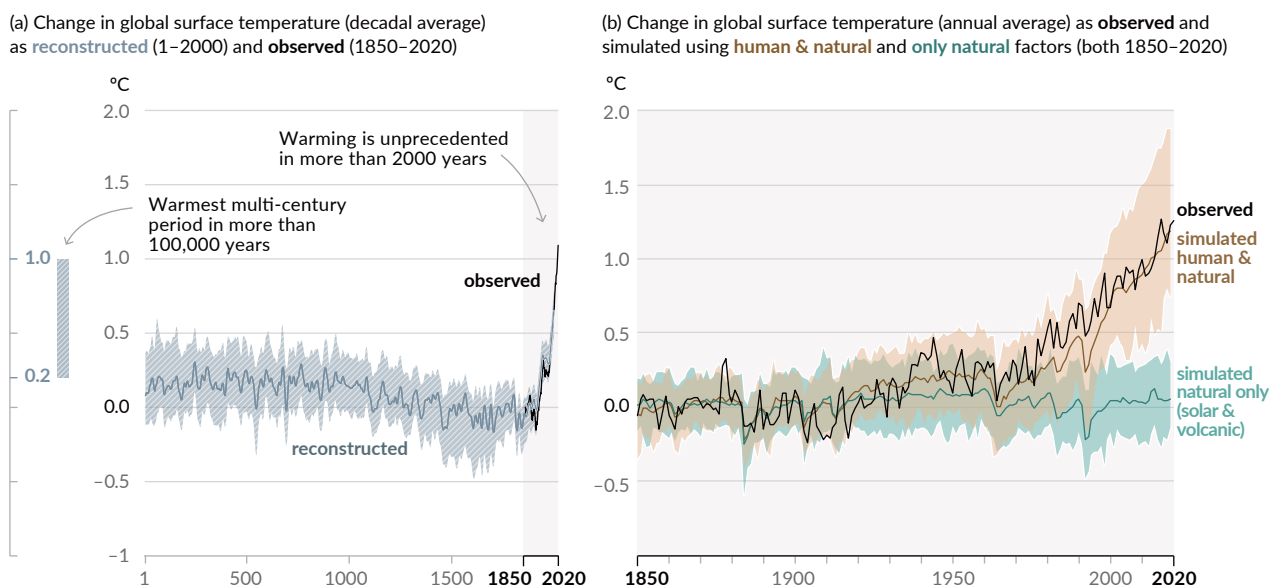


Figure SPM.1 | History of global temperature change and causes of recent warming

Panel (a) Changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, years 1–2000) and from direct observations (solid black line, 1850–2020), both relative to 1850–1900 and decadal averaged. The vertical bar on the left shows the estimated temperature (*very likely* range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the *very likely* ranges for the temperature reconstructions.

Panel (b) Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations (see Box SPM.1) of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the *very likely* range of simulations. (See Figure SPM.2 for the assessed contributions to warming).

{2.3.1; Cross-Chapter Box 2.3; 3.3; TS.2.2; Cross-Section Box TS.1, Figure 1a}

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling

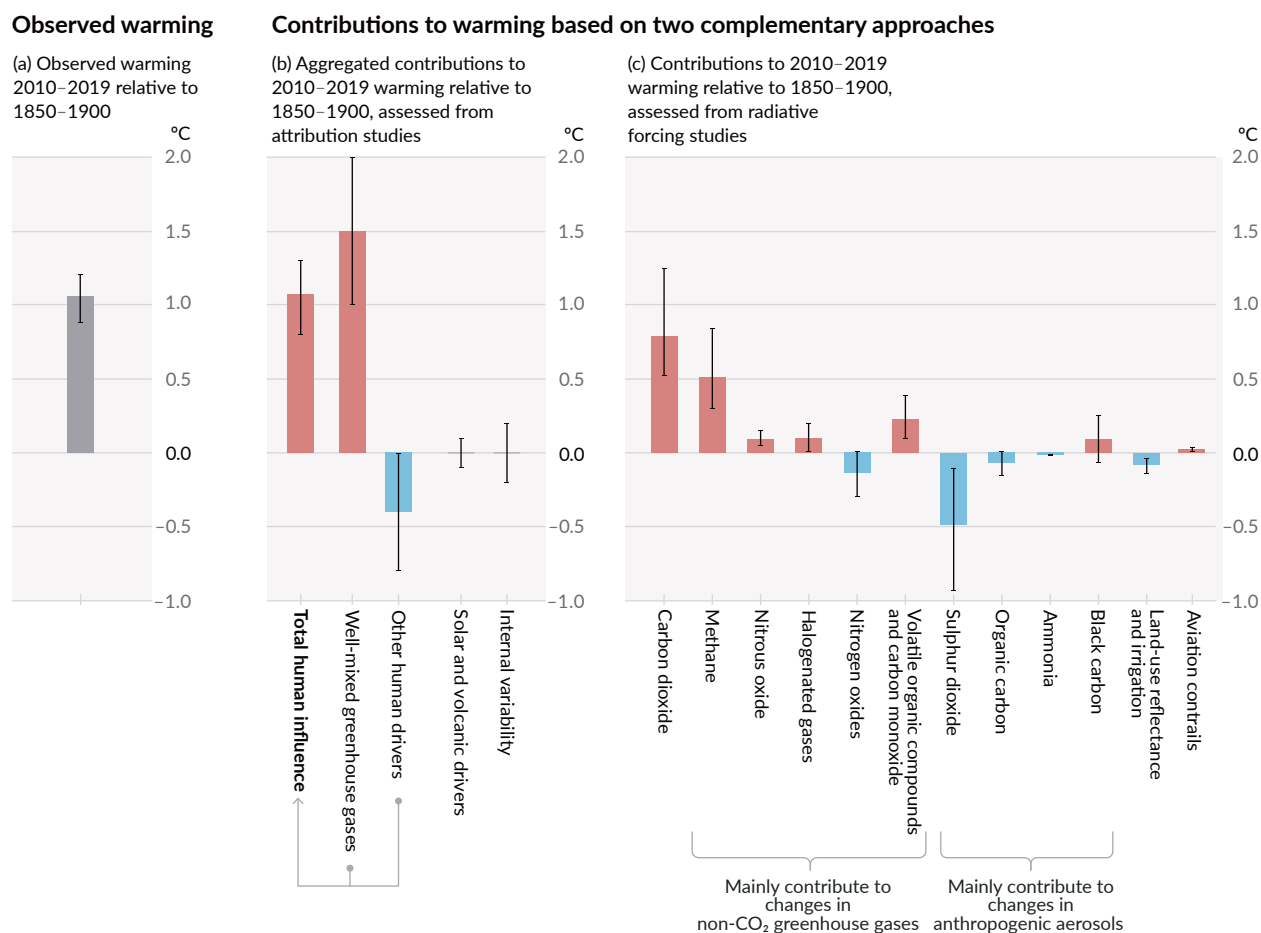


Figure SPM.2 | Assessed contributions to observed warming in 2010–2019 relative to 1850–1900

Panel (a) Observed global warming (increase in global surface temperature). Whiskers show the *very likely* range.

Panel (b) Evidence from attribution studies, which synthesize information from climate models and observations. The panel shows temperature change attributed to: total human influence; changes in well-mixed greenhouse gas concentrations; other human drivers due to aerosols, ozone and land-use change (land-use reflectance); solar and volcanic drivers; and internal climate variability. Whiskers show *likely* ranges.

Panel (c) Evidence from the assessment of radiative forcing and climate sensitivity. The panel shows temperature changes from individual components of human influence: emissions of greenhouse gases, aerosols and their precursors; land-use changes (land-use reflectance and irrigation); and aviation contrails. Whiskers show *very likely* ranges. Estimates account for both direct emissions into the atmosphere and their effect, if any, on other climate drivers. For aerosols, both direct effects (through radiation) and indirect effects (through interactions with clouds) are considered.

{Cross-Chapter Box 2.3, 3.3.1, 6.4.2, 7.3}

A.2 The scale of recent changes across the climate system as a whole – and the present state of many aspects of the climate system – are unprecedented over many centuries to many thousands of years.
{2.2, 2.3, Cross-Chapter Box 2.1, 5.1} (Figure SPM.1)

A.2.1 In 2019, atmospheric CO₂ concentrations were higher than at any time in at least 2 million years (*high confidence*), and concentrations of CH₄ and N₂O were higher than at any time in at least 800,000 years (*very high confidence*). Since 1750, increases in CO₂ (47%) and CH₄ (156%) concentrations far exceed – and increases in N₂O (23%) are similar to – the natural multi-millennial changes between glacial and interglacial periods over at least the past 800,000 years (*very high confidence*). {2.2, 5.1, TS.2.2}

A.2.2 Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). Temperatures during the most recent decade (2011–2020) exceed those of the most recent multi-century warm period, around 6500 years ago¹³ [0.2°C to 1°C relative to 1850–1900] (*medium confidence*). Prior to that, the next most recent warm period was about 125,000 years ago, when the multi-century temperature [0.5°C to 1.5°C relative to 1850–1900] overlaps the observations of the most recent decade (*medium confidence*). {2.3, Cross-Chapter Box 2.1, Cross-Section Box TS.1} (Figure SPM.1)

A.2.3 In 2011–2020, annual average Arctic sea ice area reached its lowest level since at least 1850 (*high confidence*). Late summer Arctic sea ice area was smaller than at any time in at least the past 1000 years (*medium confidence*). The global nature of glacier retreat since the 1950s, with almost all of the world's glaciers retreating synchronously, is unprecedented in at least the last 2000 years (*medium confidence*). {2.3, TS.2.5}

A.2.4 Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years (*high confidence*). The global ocean has warmed faster over the past century than since the end of the last deglacial transition (around 11,000 years ago) (*medium confidence*). A long-term increase in surface open ocean pH occurred over the past 50 million years (*high confidence*). However, surface open ocean pH as low as recent decades is unusual in the last 2 million years (*medium confidence*). {2.3, TS.2.4, Box TS.4}

A.3 Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5.
{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, Box 9.2, 10.6, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.9, 12.3} (Figure SPM.3)

A.3.1 It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver¹⁴ of these changes. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006. {Box 9.2, 11.2, 11.3, 11.9, TS.2.4, TS.2.6, Box TS.10} (Figure SPM.3)

A.3.2 The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis (*high confidence*), and human-induced climate change is *likely* the main driver. Human-induced climate change has contributed to increases in agricultural and ecological droughts¹⁵ in some regions due to increased land evapotranspiration¹⁶ (*medium confidence*). {8.2, 8.3, 11.4, 11.6, 11.9, TS.2.6, Box TS.10} (Figure SPM.3)

13 As stated in section B.1, even under the very low emissions scenario SSP1-1.9, temperatures are assessed to remain elevated above those of the most recent decade until at least 2100 and therefore warmer than the century-scale period 6500 years ago.

14 As indicated in footnote 12, throughout this SPM, 'main driver' means responsible for more than 50% of the change.

15 Agricultural and ecological drought (depending on the affected biome): a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general (see Annex VII: Glossary). Observed changes in meteorological droughts (precipitation deficits) and hydrological droughts (streamflow deficits) are distinct from those in agricultural and ecological droughts and are addressed in the underlying AR6 material (Chapter 11).

16 The combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soils and vegetation that make up the Earth's surface (Glossary).

- A.3.3 Decreases in global land monsoon precipitation¹⁷ from the 1950s to the 1980s are partly attributed to human-caused Northern Hemisphere aerosol emissions, but increases since then have resulted from rising GHG concentrations and decadal to multi-decadal internal variability (*medium confidence*). Over South Asia, East Asia and West Africa, increases in monsoon precipitation due to warming from GHG emissions were counteracted by decreases in monsoon precipitation due to cooling from human-caused aerosol emissions over the 20th century (*high confidence*). Increases in West African monsoon precipitation since the 1980s are partly due to the growing influence of GHGs and reductions in the cooling effect of human-caused aerosol emissions over Europe and North America (*medium confidence*).
{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, 10.6, Box TS.13}
- A.3.4 It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and it is *very likely* that the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone (*medium confidence*). There is *low confidence* in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones (*high confidence*), but data limitations inhibit clear detection of past trends on the global scale.
{8.2, 11.7, Box TS.10}
- A.3.5 Human influence has *likely* increased the chance of compound extreme events¹⁸ since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (*high confidence*), fire weather in some regions of all inhabited continents (*medium confidence*), and compound flooding in some locations (*medium confidence*).
{11.6, 11.7, 11.8, 12.3, 12.4, TS.2.6, Table TS.5, Box TS.10}

¹⁷ The global monsoon is defined as the area in which the annual range (local summer minus local winter) of precipitation is greater than 2.5 mm day⁻¹ (Glossary). Global land monsoon precipitation refers to the mean precipitation over land areas within the global monsoon.

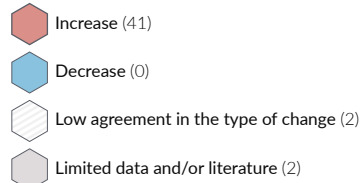
¹⁸ Compound extreme events are the combination of multiple drivers and/or hazards that contribute to societal or environmental risk (Glossary). Examples are concurrent heatwaves and droughts, compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow), compound fire weather conditions (i.e., a combination of hot, dry and windy conditions), or concurrent extremes at different locations.

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

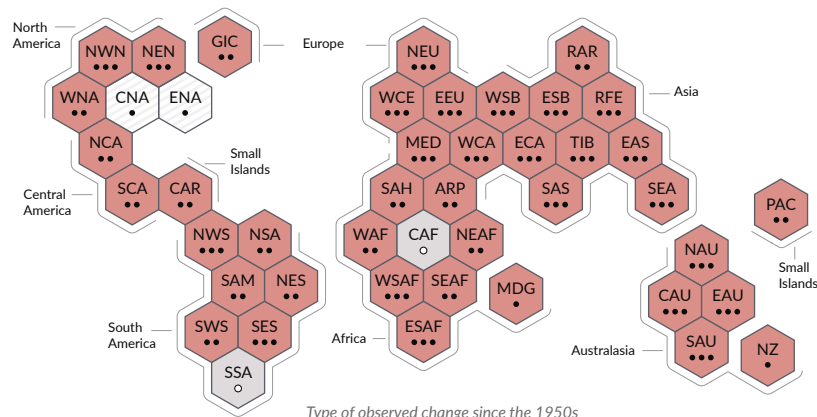
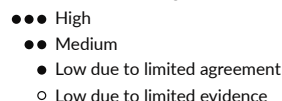
SPM

(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in hot extremes



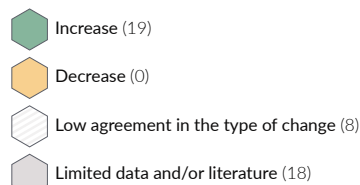
Confidence in human contribution to the observed change



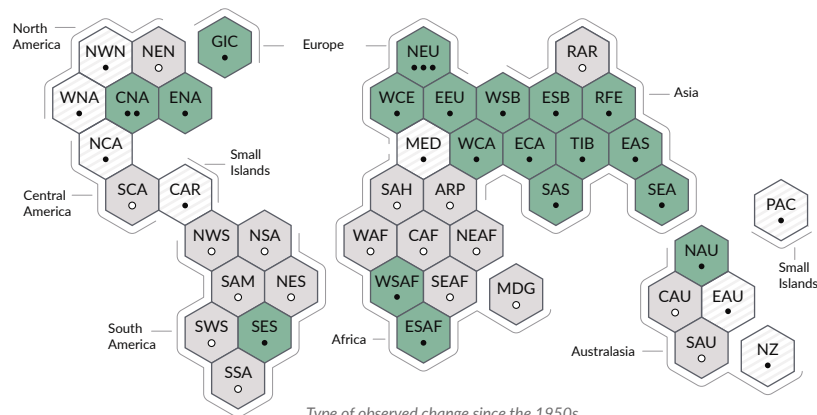
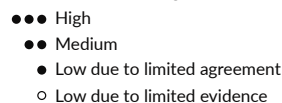
Type of observed change since the 1950s

(b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in heavy precipitation



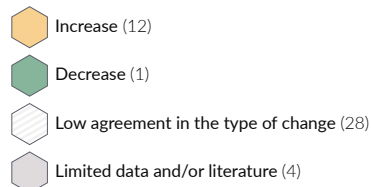
Confidence in human contribution to the observed change



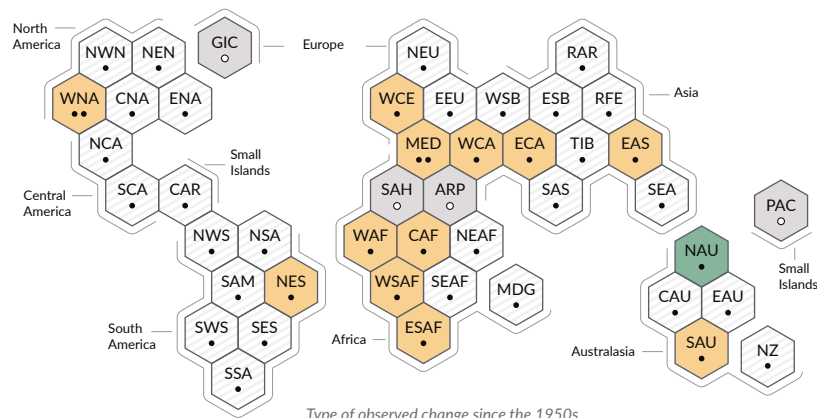
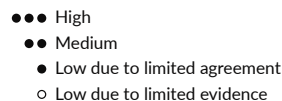
Type of observed change since the 1950s

(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in agricultural and ecological drought



Confidence in human contribution to the observed change



Type of observed change since the 1950s

Each hexagon corresponds to one of the IPCC AR6 WGI reference regions



IPCC AR6 WGI reference regions: **North America:** NWN (North-Western North America), NEN (North-Eastern North America), WNA (Western North America), CNA (Central North America), ENA (Eastern North America), **Central America:** NCA (Northern Central America), SCA (Southern Central America), CAR (Caribbean), **South America:** NWS (North-Western South America), NSA (Northern South America), NES (North-Eastern South America), SAM (South American Monsoon), SWS (South-Western South America), SES (South-Eastern South America), SSA (Southern South America), **Europe:** GIC (Greenland/Iceland), NEU (Northern Europe), WCE (Western and Central Europe), EEU (Eastern Europe), MED (Mediterranean), **Africa:** MED (Mediterranean), SAH (Sahara), WAF (Western Africa), CAF (Central Africa), NEAF (North Eastern Africa), SEAF (South Eastern Africa), WSAF (West Southern Africa), ESAF (East Southern Africa), MDG (Madagascar), **Asia:** RAR (Russian Arctic), WSB (West Siberia), ESB (East Siberia), RFE (Russian Far East), WCA (West Central Asia), ECA (East Central Asia), TIB (Tibetan Plateau), EAS (East Asia), ARP (Arabian Peninsula), SAS (South East Asia), SEA (South East Asia), **Australasia:** NAU (Northern Australia), CAU (Central Australia), EAU (Eastern Australia), SAU (Southern Australia), NZ (New Zealand), **Small Islands:** CAR (Caribbean), PAC (Pacific Small Islands)

Figure SPM.3 | Synthesis of assessed observed and attributable regional changes

The IPCC AR6 WGI inhabited regions are displayed as **hexagons** with identical size in their approximate geographical location (see legend for regional acronyms). All assessments are made for each region as a whole and for the 1950s to the present. Assessments made on different time scales or more local spatial scales might differ from what is shown in the figure. The **colours** in each panel represent the four outcomes of the assessment on observed changes. Striped hexagons (white and light-grey) are used where there is *low agreement* in the type of change for the region as a whole, and grey hexagons are used when there is limited data and/or literature that prevents an assessment of the region as a whole. Other colours indicate at least *medium confidence* in the observed change. The **confidence level** for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots: three dots for *high confidence*, two dots for *medium confidence* and one dot for *low confidence* (single, filled dot: limited agreement; single, empty dot: limited evidence).

Panel (a) For hot extremes, the evidence is mostly drawn from changes in metrics based on daily maximum temperatures; regional studies using other indices (heatwave duration, frequency and intensity) are used in addition. Red hexagons indicate regions where there is at least *medium confidence* in an observed increase in hot extremes.

Panel (b) For heavy precipitation, the evidence is mostly drawn from changes in indices based on one-day or five-day precipitation amounts using global and regional studies. Green hexagons indicate regions where there is at least *medium confidence* in an observed increase in heavy precipitation.

Panel (c) Agricultural and ecological droughts are assessed based on observed and simulated changes in total column soil moisture, complemented by evidence on changes in surface soil moisture, water balance (precipitation minus evapotranspiration) and indices driven by precipitation and atmospheric evaporative demand. Yellow hexagons indicate regions where there is at least *medium confidence* in an observed increase in this type of drought, and green hexagons indicate regions where there is at least *medium confidence* in an observed decrease in agricultural and ecological drought.

For all regions, Table TS.5 shows a broader range of observed changes besides the ones shown in this figure. Note that Southern South America (SSA) is the only region that does not display observed changes in the metrics shown in this figure, but is affected by observed increases in mean temperature, decreases in frost and increases in marine heatwaves.

{11.9, Atlas 1.3.3, Figure Atlas.2, Table TS.5; Box TS.10, Figure 1}

A.4 Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3°C, with a narrower range compared to AR5.

{2.2, 7.3, 7.4, 7.5, Box 7.2, 9.4, 9.5, 9.6, Cross-Chapter Box 9.1}

- A.4.1** Human-caused radiative forcing of 2.72 [1.96 to 3.48] W m⁻² in 2019 relative to 1750 has warmed the climate system. This warming is mainly due to increased GHG concentrations, partly reduced by cooling due to increased aerosol concentrations. The radiative forcing has increased by 0.43 W m⁻² (19%) relative to AR5, of which 0.34 W m⁻² is due to the increase in GHG concentrations since 2011. The remainder is due to improved scientific understanding and changes in the assessment of aerosol forcing, which include decreases in concentration and improvement in its calculation (*high confidence*). {2.2, 7.3, TS.2.2, TS.3.1}
- A.4.2** Human-caused net positive radiative forcing causes an accumulation of additional energy (heating) in the climate system, partly reduced by increased energy loss to space in response to surface warming. The observed average rate of heating of the climate system increased from 0.50 [0.32 to 0.69] W m⁻² for the period 1971–2006¹⁹ to 0.79 [0.52 to 1.06] W m⁻² for the period 2006–2018²⁰ (*high confidence*). Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (*high confidence*). {7.2, Box 7.2, TS.3.1}
- A.4.3** Heating of the climate system has caused global mean sea level rise through ice loss on land and thermal expansion from ocean warming. Thermal expansion explained 50% of sea level rise during 1971–2018, while ice loss from glaciers contributed 22%, ice sheets 20% and changes in land-water storage 8%. The rate of ice-sheet loss increased by a factor of four between 1992–1999 and 2010–2019. Together, ice-sheet and glacier mass loss were the dominant contributors to global mean sea level rise during 2006–2018 (*high confidence*). {9.4, 9.5, 9.6, Cross-Chapter Box 9.1}
- A.4.4** The equilibrium climate sensitivity is an important quantity used to estimate how the climate responds to radiative forcing. Based on multiple lines of evidence,²¹ the *very likely* range of equilibrium climate sensitivity is between 2°C (*high confidence*) and 5°C (*medium confidence*). The AR6 assessed best estimate is 3°C with a *likely* range of 2.5°C to 4°C (*high confidence*), compared to 1.5°C to 4.5°C in AR5, which did not provide a best estimate. {7.4, 7.5, TS.3.2}

19 Cumulative energy increase of 282 [177 to 387] ZJ over 1971–2006 (1 ZJ = 10²¹ joules).

20 Cumulative energy increase of 152 [100 to 205] ZJ over 2006–2018.

21 Understanding of climate processes, the instrumental record, paleoclimates and model-based emergent constraints (Glossary).

B. Possible Climate Futures

A set of five new illustrative emissions scenarios is considered consistently across this Report to explore the climate response to a broader range of greenhouse gas (GHG), land-use and air pollutant futures than assessed in AR5. This set of scenarios drives climate model projections of changes in the climate system. These projections account for solar activity and background forcing from volcanoes. Results over the 21st century are provided for the near term (2021–2040), mid-term (2041–2060) and long term (2081–2100) relative to 1850–1900, unless otherwise stated.

Box SPM.1 | Scenarios, Climate Models and Projections

Box SPM.1.1: This Report assesses the climate response to five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. They start in 2015, and include scenarios²² with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO₂ emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO₂ emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions and CO₂ emissions declining to net zero around or after 2050, followed by varying levels of net negative CO₂ emissions²³ (SSP1-1.9 and SSP1-2.6), as illustrated in Figure SPM.4. Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls. Alternative assumptions may result in similar emissions and climate responses, but the socio-economic assumptions and the feasibility or likelihood of individual scenarios are not part of the assessment.

{1.6, Cross-Chapter Box 1.4, TS.1.3} (Figure SPM.4)

Box SPM.1.2: This Report assesses results from climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme. These models include new and better representations of physical, chemical and biological processes, as well as higher resolution, compared to climate models considered in previous IPCC assessment reports. This has improved the simulation of the recent mean state of most large-scale indicators of climate change and many other aspects across the climate system. Some differences from observations remain, for example in regional precipitation patterns. The CMIP6 historical simulations assessed in this Report have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the *very likely* range of the CMIP6 ensemble. However, some CMIP6 models simulate a warming that is either above or below the assessed *very likely* range of observed warming.

{1.5, Cross-Chapter Box 2.2, 3.3, 3.8, TS.1.2, Cross-Section Box TS.1} (Figure SPM.1b, Figure SPM.2)

Box SPM.1.3: The CMIP6 models considered in this Report have a wider range of climate sensitivity than in CMIP5 models and the AR6 assessed *very likely* range, which is based on multiple lines of evidence. These CMIP6 models also show a higher average climate sensitivity than CMIP5 and the AR6 assessed best estimate. The higher CMIP6 climate sensitivity values compared to CMIP5 can be traced to an amplifying cloud feedback that is larger in CMIP6 by about 20%.

{Box 7.1, 7.3, 7.4, 7.5, TS.3.2}

Box SPM.1.4: For the first time in an IPCC report, assessed future changes in global surface temperature, ocean warming and sea level are constructed by combining multi-model projections with observational constraints based on past simulated warming, as well as the AR6 assessment of climate sensitivity. For other quantities, such robust methods do not yet exist to constrain the projections. Nevertheless, robust projected geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached.

{1.6, 4.3, 4.6, Box 4.1, 7.5, 9.2, 9.6, Cross-Chapter Box 11.1, Cross-Section Box TS.1}

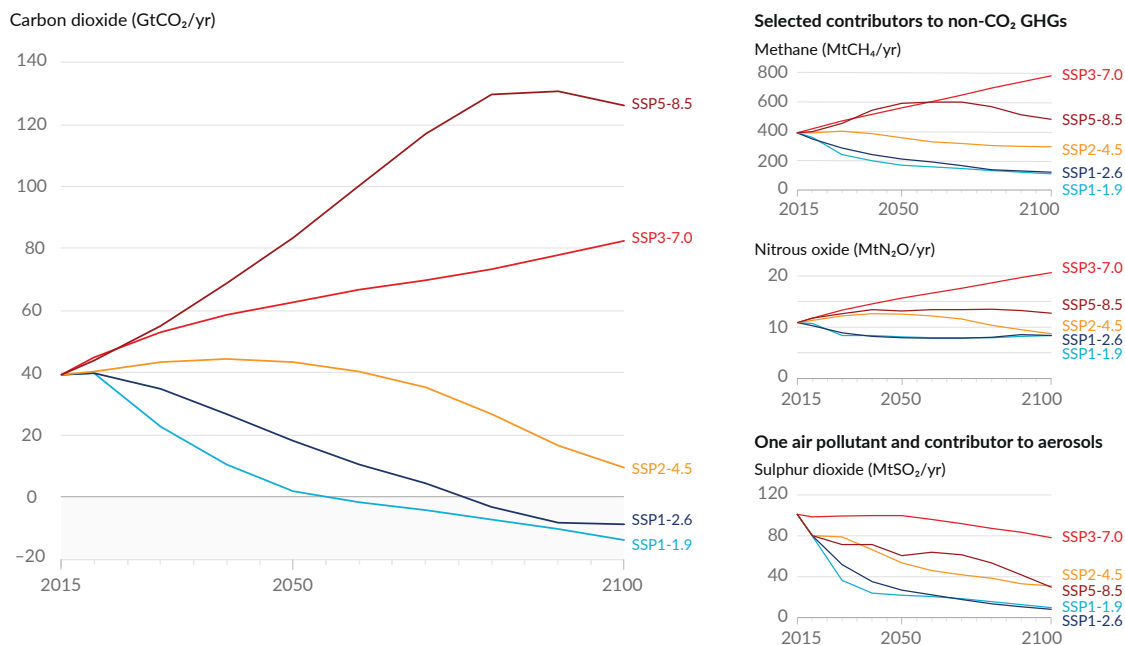
22 Throughout this Report, the five illustrative scenarios are referred to as SSPx-y, where ‘SSPx’ refers to the Shared Socio-economic Pathway or ‘SSP’ describing the socio-economic trends underlying the scenario, and ‘y’ refers to the approximate level of radiative forcing (in watts per square metre, or W m⁻²) resulting from the scenario in the year 2100. A detailed comparison to scenarios used in earlier IPCC reports is provided in Section TS.1.3, and Sections 1.6 and 4.6. The SSPs that underlie the specific forcing scenarios used to drive climate models are not assessed by WGI. Rather, the SSPx-y labelling ensures traceability to the underlying literature in which specific forcing pathways are used as input to the climate models. IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

23 Net negative CO₂ emissions are reached when anthropogenic removals of CO₂ exceed anthropogenic emissions (Glossary).

Box SPM.1 (continued)

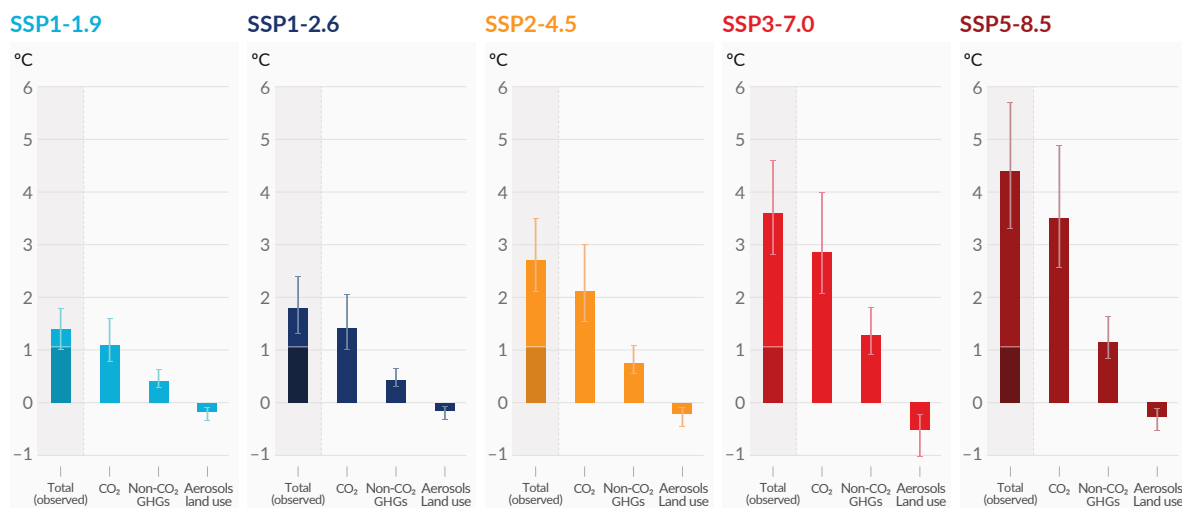
Future emissions cause future additional warming, with total warming dominated by past and future CO₂ emissions

(a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios



(b) Contribution to global surface temperature increase from different emissions, with a dominant role of CO₂ emissions

Change in global surface temperature in 2081–2100 relative to 1850–1900 (°C)



Total warming (observed warming to date in darker shade), warming from CO₂, warming from non-CO₂ GHGs and cooling from changes in aerosols and land use

Figure SPM.4 | Future anthropogenic emissions of key drivers of climate change and warming contributions by groups of drivers for the five illustrative scenarios used in this report

The five scenarios are SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5.

Panel (a) Annual anthropogenic (human-caused) emissions over the 2015–2100 period. Shown are emissions trajectories for carbon dioxide (CO₂) from all sectors (GtCO₂/yr) (left graph) and for a subset of three key non-CO₂ drivers considered in the scenarios: methane (CH₄, MtCH₄/yr, top-right graph); nitrous oxide (N₂O, MtN₂O/yr, middle-right graph); and sulphur dioxide (SO₂, MtSO₂/yr, bottom-right graph), contributing to anthropogenic aerosols in panel (b).

Panel (b) Warming contributions by groups of anthropogenic drivers and by scenario are shown as the change in global surface temperature (°C) in 2081–2100 relative to 1850–1900, with indication of the observed warming to date. Bars and whiskers represent median values and the *very likely* range, respectively. Within each scenario bar plot, the bars represent: total global warming (°C; ‘total’ bar) (see Table SPM.1); warming contributions (°C) from changes in CO₂ (‘CO₂’ bar) and from non-CO₂ greenhouse gases (GHGs; ‘non-CO₂ GHGs’ bar: comprising well-mixed greenhouse gases and ozone); and net cooling from other anthropogenic drivers (‘aerosols and land use’ bar: anthropogenic aerosols, changes in reflectance due to land-use and irrigation changes, and contrails from aviation) (see Figure SPM.2, panel c, for the warming contributions to date for individual drivers). The best estimate for observed warming in 2010–2019 relative to 1850–1900 (see Figure SPM.2, panel a) is indicated in the darker column in the ‘total’ bar. Warming contributions in panel (b) are calculated as explained in Table SPM.1 for the total bar. For the other bars, the contribution by groups of drivers is calculated with a physical climate emulator of global surface temperature that relies on climate sensitivity and radiative forcing assessments. [Cross-Chapter Box 1.4; 4.6; Figure 4.35; 6.7; Figures 6.18, 6.22 and 6.24; 7.3; Cross-Chapter Box 7.1; Figure 7.7; Box TS.7; Figures TS.4 and TS.15]

B.1 Global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO₂ and other greenhouse gas emissions occur in the coming decades.

{2.3, Cross-Chapter Box 2.3, Cross-Chapter Box 2.4, 4.3, 4.4, 4.5} (Figure SPM.1, Figure SPM.4, Figure SPM.8, Table SPM.1, Box SPM.1)

- B.1.1** Compared to 1850–1900, global surface temperature averaged over 2081–2100 is *very likely* to be higher by 1.0°C to 1.8°C under the very low GHG emissions scenario considered (SSP1-1.9), by 2.1°C to 3.5°C in the intermediate GHG emissions scenario (SSP2-4.5) and by 3.3°C to 5.7°C under the very high GHG emissions scenario (SSP5-8.5).²⁴ The last time global surface temperature was sustained at or above 2.5°C higher than 1850–1900 was over 3 million years ago (*medium confidence*).

{2.3, Cross-Chapter Box 2.4, 4.3, 4.5, Box TS.2, Box TS.4, Cross-Section Box TS.1} (Table SPM.1)

Table SPM.1 | Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to +0.12] °C than in AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014. [Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1]

Scenario	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
	Best estimate (°C)	<i>Very likely</i> range (°C)	Best estimate (°C)	<i>Very likely</i> range (°C)	Best estimate (°C)	<i>Very likely</i> range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

- B.1.2** Based on the assessment of multiple lines of evidence, global warming of 2°C, relative to 1850–1900, would be exceeded during the 21st century under the high and very high GHG emissions scenarios considered in this report (SSP3-7.0 and SSP5-8.5, respectively). Global warming of 2°C would *extremely likely* be exceeded in the intermediate GHG emissions scenario (SSP2-4.5). Under the very low and low GHG emissions scenarios, global warming of 2°C is *extremely unlikely* to be exceeded (SSP1-1.9) or *unlikely* to be exceeded (SSP1-2.6).²⁵ Crossing the 2°C global warming level in the mid-term period (2041–2060) is *very likely* to occur under the very high GHG emissions scenario (SSP5-8.5), *likely* to occur under the high GHG emissions scenario (SSP3-7.0), and *more likely than not* to occur in the intermediate GHG emissions scenario (SSP2-4.5).²⁶

{4.3, Cross-Section Box TS.1} (Table SPM.1, Figure SPM.4, Box SPM.1)

²⁴ Changes in global surface temperature are reported as running 20-year averages, unless stated otherwise.

²⁵ SSP1-1.9 and SSP1-2.6 are scenarios that start in 2015 and have very low and low GHG emissions, respectively, and CO₂ emissions declining to net zero around or after 2050, followed by varying levels of net negative CO₂ emissions.

²⁶ Crossing is defined here as having the assessed global surface temperature change, averaged over a 20-year period, exceed a particular global warming level.

- B.1.3 Global warming of 1.5°C relative to 1850–1900 would be exceeded during the 21st century under the intermediate, high and very high GHG emissions scenarios considered in this report (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9).²⁷ Furthermore, for the very low GHG emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.
{4.3, Cross-Section Box TS.1} (Table SPM.1, Figure SPM.4)
- B.1.4 Global surface temperature in any single year can vary above or below the long-term human-induced trend, due to substantial natural variability.²⁸ The occurrence of individual years with global surface temperature change above a certain level, for example 1.5°C or 2°C, relative to 1850–1900 does not imply that this global warming level has been reached.²⁹
{Cross-Chapter Box 2.3, 4.3, 4.4, Box 4.1, Cross-Section Box TS.1} (Table SPM.1, Figure SPM.1, Figure SPM.8)
- B.2 Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation, and, in some regions, agricultural and ecological droughts; an increase in the proportion of intense tropical cyclones; and reductions in Arctic sea ice, snow cover and permafrost.**
{4.3, 4.5, 4.6, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, Box 9.2, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11} (Figure SPM.5, Figure SPM.6, Figure SPM.8)
- B.2.1 It is *virtually certain* that the land surface will continue to warm more than the ocean surface (*likely* 1.4 to 1.7 times more). It is *virtually certain* that the Arctic will continue to warm more than global surface temperature, with *high confidence* above two times the rate of global warming.
{2.3, 4.3, 4.5, 4.6, 7.4, 11.1, 11.3, 11.9, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Section Box TS.1, TS.2.6} (Figure SPM.5)
- B.2.2 With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts³⁰ in some regions (*high confidence*). Discernible changes in intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5°C of global warming (*medium confidence*). Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions (*medium confidence*). There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5°C of global warming. Projected percentage changes in frequency are larger for rarer events (*high confidence*).
{8.2, 11.2, 11.3, 11.4, 11.6, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, TS.2.6} (Figure SPM.5, Figure SPM.6)
- B.2.3 Some mid-latitude and semi-arid regions, and the South American Monsoon region, are projected to see the highest increase in the temperature of the hottest days, at about 1.5 to 2 times the rate of global warming (*high confidence*). The Arctic is projected to experience the highest increase in the temperature of the coldest days, at about three times the rate of global warming (*high confidence*). With additional global warming, the frequency of marine heatwaves will continue to increase (*high confidence*), particularly in the tropical ocean and the Arctic (*medium confidence*).
{Box 9.2, 11.1, 11.3, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, 12.4, TS.2.4, TS.2.6} (Figure SPM.6)

27 The AR6 assessment of when a given global warming level is first exceeded benefits from the consideration of the illustrative scenarios, the multiple lines of evidence entering the assessment of future global surface temperature response to radiative forcing, and the improved estimate of historical warming. The AR6 assessment is thus not directly comparable to the SR1.5 SPM, which reported *likely* reaching 1.5°C global warming between 2030 and 2052, from a simple linear extrapolation of warming rates of the recent past. When considering scenarios similar to SSP1-1.9 instead of linear extrapolation, the SR1.5 estimate of when 1.5°C global warming is first exceeded is close to the best estimate reported here.

28 Natural variability refers to climatic fluctuations that occur without any human influence, that is, internal variability combined with the response to external natural factors such as volcanic eruptions, changes in solar activity and, on longer time scales, orbital effects and plate tectonics (Glossary).

29 The internal variability in any single year is estimated to be about $\pm 0.25^\circ\text{C}$ (5–95% range, *high confidence*).

30 Projected changes in agricultural and ecological droughts are primarily assessed based on total column soil moisture. See footnote 15 for definition and relation to precipitation and evapotranspiration.

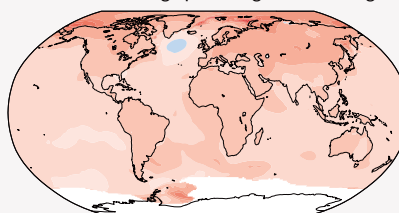
- B.2.4 It is *very likely* that heavy precipitation events will intensify and become more frequent in most regions with additional global warming. At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming (*high confidence*). The proportion of intense tropical cyclones (Category 4–5) and peak wind speeds of the most intense tropical cyclones are projected to increase at the global scale with increasing global warming (*high confidence*). {8.2, 11.4, 11.7, 11.9, Cross-Chapter Box 11.1, Box TS.6, TS.4.3.1} (Figure SPM.5, Figure SPM.6)
- B.2.5 Additional warming is projected to further amplify permafrost thawing and loss of seasonal snow cover, of land ice and of Arctic sea ice (*high confidence*). The Arctic is *likely* to be practically sea ice-free in September³¹ at least once before 2050 under the five illustrative scenarios considered in this report, with more frequent occurrences for higher warming levels. There is *low confidence* in the projected decrease of Antarctic sea ice. {4.3, 4.5, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, 12.4, Cross-Chapter Box 12.1, Atlas.5, Atlas.6, Atlas.8, Atlas.9, Atlas.11, TS.2.5} (Figure SPM.8)

With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture

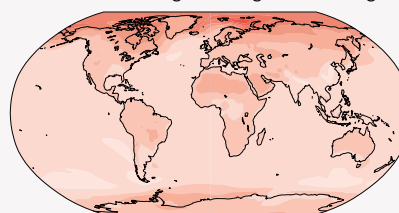
(a) Annual mean temperature change (°C) at 1°C global warming

Warming at 1°C affects all continents and is generally larger over land than over the oceans in both observations and models. Across most regions, observed and simulated patterns are consistent.

Observed change per 1°C global warming



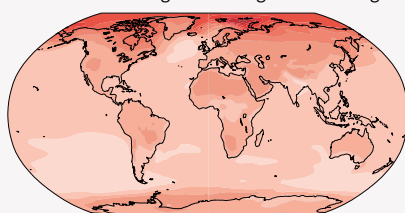
Simulated change at 1°C global warming



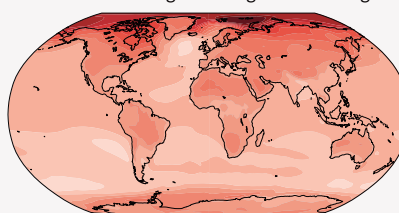
(b) Annual mean temperature change (°C) relative to 1850–1900

Across warming levels, land areas warm more than ocean areas, and the Arctic and Antarctica warm more than the tropics.

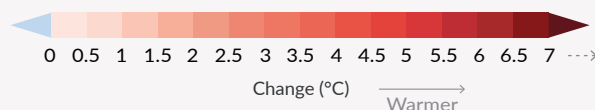
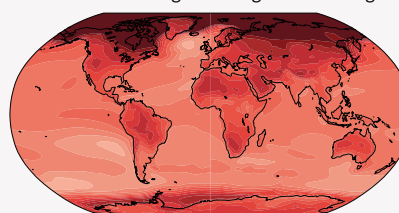
Simulated change at 1.5°C global warming



Simulated change at 2°C global warming



Simulated change at 4°C global warming



31 Monthly average sea ice area of less than 1 million km², which is about 15% of the average September sea ice area observed in 1979–1988.

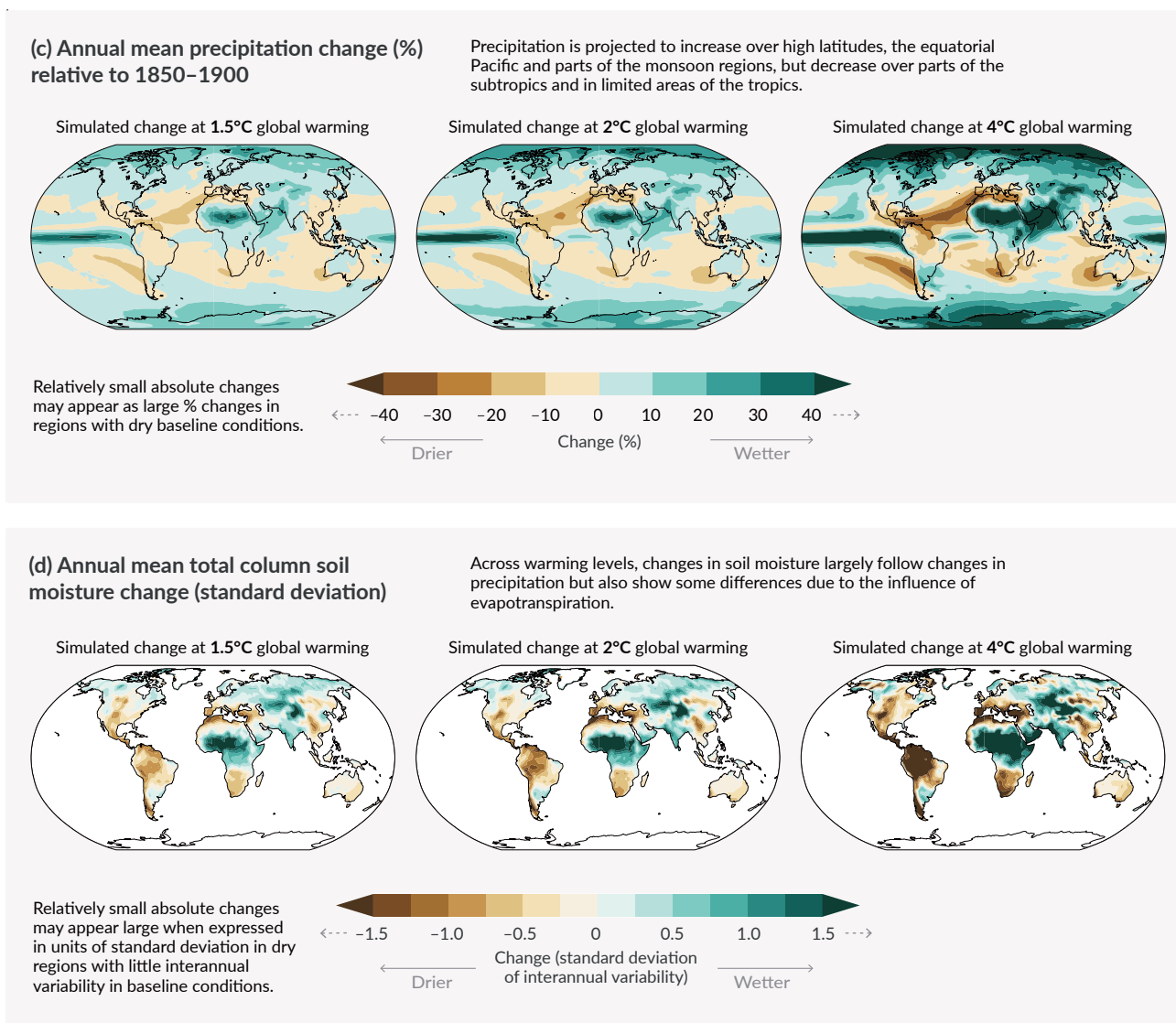


Figure SPM.5 | Changes in annual mean surface temperature, precipitation, and soil moisture

Panel (a) Comparison of observed and simulated annual mean surface temperature change. The **left map** shows the observed changes in annual mean surface temperature in the period 1850–2020 per °C of global warming (°C). The local (i.e., grid point) observed annual mean surface temperature changes are linearly regressed against the global surface temperature in the period 1850–2020. Observed temperature data are from Berkeley Earth, the dataset with the largest coverage and highest horizontal resolution. Linear regression is applied to all years for which data at the corresponding grid point is available. The regression method was used to take into account the complete observational time series and thereby reduce the role of internal variability at the grid point level. White indicates areas where time coverage was 100 years or less and thereby too short to calculate a reliable linear regression. The **right map** is based on model simulations and shows change in annual multi-model mean simulated temperatures at a global warming level of 1°C (20-year mean global surface temperature change relative to 1850–1900). The triangles at each end of the colour bar indicate out-of-bound values, that is, values above or below the given limits.

Panel (b) Simulated annual mean temperature change (°C), panel (c) precipitation change (%), and panel (d) total column soil moisture change (standard deviation of interannual variability) at global warming levels of 1.5°C, 2°C and 4°C (20-year mean global surface temperature change relative to 1850–1900). Simulated changes correspond to Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model mean change (median change for soil moisture) at the corresponding global warming level, that is, the same method as for the right map in panel (a).

In **panel (c)**, high positive percentage changes in dry regions may correspond to small absolute changes. In **panel (d)**, the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterizing drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850–1900. In panel (d), large changes in dry regions with little interannual variability in the baseline conditions can correspond to small absolute change. The triangles at each end of the colour bars indicate out-of-bound values, that is, values above or below the given limits. Results from all models reaching the corresponding warming level in any of the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are averaged. Maps of annual mean temperature and precipitation changes at a global warming level of 3°C are available in Figure 4.31 and Figure 4.32 in Section 4.6. Corresponding maps of panels (b), (c) and (d), including hatching to indicate the level of model agreement at grid-cell level, are found in Figures 4.31, 4.32 and 11.19, respectively; as highlighted in Cross-Chapter Box Atlas.1, grid-cell level hatching is not informative for larger spatial scales (e.g., over AR6 reference regions) where the aggregated signals are less affected by small-scale variability, leading to an increase in robustness.

{Figure 1.14, 4.6.1, Cross-Chapter Box 11.1, Cross-Chapter Box Atlas.1, TS.1.3.2, Figures TS.3 and TS.5}

Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

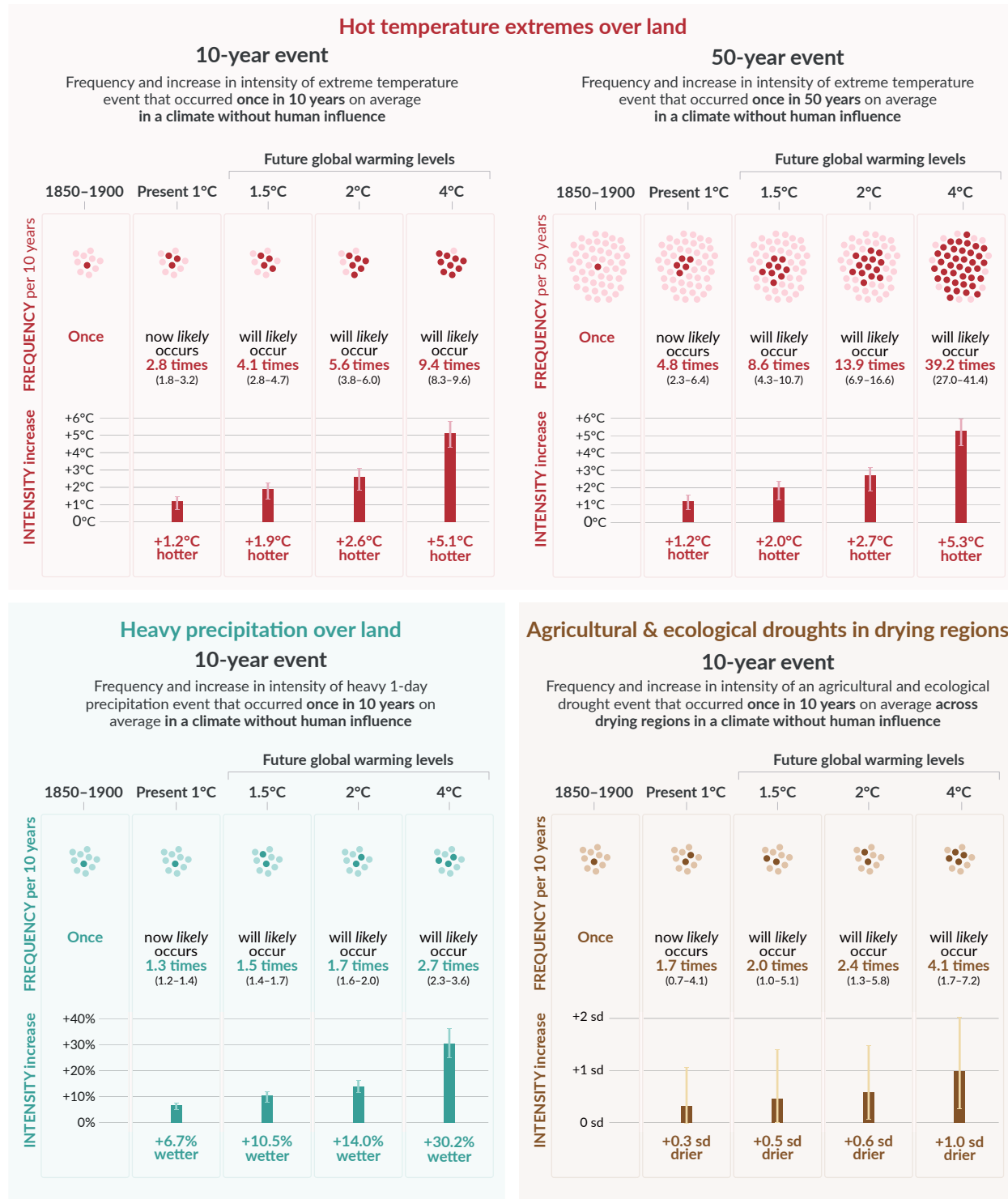


Figure SPM.6 | Projected changes in the intensity and frequency of hot temperature extremes over land, extreme precipitation over land, and agricultural and ecological droughts in drying regions

Projected changes are shown at global warming levels of 1°C, 1.5°C, 2°C, and 4°C and are relative to 1850–1900,⁹ representing a climate without human influence. The figure depicts frequencies and increases in intensity of 10- or 50-year extreme events from the base period (1850–1900) under different global warming levels.

Hot temperature extremes are defined as the daily maximum temperatures over land that were exceeded on average once in a decade (10-year event) or once in 50 years (50-year event) during the 1850–1900 reference period. **Extreme precipitation events** are defined as the daily precipitation amount over land that

was exceeded on average once in a decade during the 1850–1900 reference period. **Agricultural and ecological drought events** are defined as the annual average of total column soil moisture below the 10th percentile of the 1850–1900 base period. These extremes are defined on model grid box scale. For hot temperature extremes and extreme precipitation, results are shown for the global land. For agricultural and ecological drought, results are shown for drying regions only, which correspond to the AR6 regions in which there is at least *medium confidence* in a projected increase in agricultural and ecological droughts at the 2°C warming level compared to the 1850–1900 base period in the Coupled Model Intercomparison Project Phase 6 (CMIP6). These regions include Western North America, Central North America, Northern Central America, Southern Central America, Caribbean, Northern South America, North-Eastern South America, South American Monsoon, South-Western South America, Southern South America, Western and Central Europe, Mediterranean, West Southern Africa, East Southern Africa, Madagascar, Eastern Australia, and Southern Australia (Caribbean is not included in the calculation of the figure because of the too-small number of full land grid cells). The non-drying regions do not show an overall increase or decrease in drought severity. Projections of changes in agricultural and ecological droughts in the CMIP Phase 5 (CMIP5) multi-model ensemble differ from those in CMIP6 in some regions, including in parts of Africa and Asia. Assessments of projected changes in meteorological and hydrological droughts are provided in Chapter 11.

In the **'frequency' section**, each year is represented by a dot. The dark dots indicate years in which the extreme threshold is exceeded, while light dots are years when the threshold is not exceeded. Values correspond to the medians (in bold) and their respective *likely* ranges based on the 5–95% range of the multi-model ensemble from simulations of CMIP6 under different Shared Socio-economic Pathway scenarios. For consistency, the number of dark dots is based on the rounded-up median. In the **'intensity' section**, medians and their *likely* ranges, also based on the 5–95% range of the multi-model ensemble from simulations of CMIP6, are displayed as dark and light bars, respectively. Changes in the intensity of hot temperature extremes and extreme precipitation are expressed as degree Celsius and percentage. As for agricultural and ecological drought, intensity changes are expressed as fractions of standard deviation of annual soil moisture.

{11.1; 11.3; 11.4; 11.6; 11.9; Figures 11.12, 11.15, 11.6, 11.7, and 11.18}

B.3 Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.

{4.3, 4.4, 4.5, 4.6, 8.2, 8.3, 8.4, 8.5, Box 8.2, 11.4, 11.6, 11.9, 12.4, Atlas.3} (Figure SPM.5, Figure SPM.6)

B.3.1 There is strengthened evidence since AR5 that the global water cycle will continue to intensify as global temperatures rise (*high confidence*), with precipitation and surface water flows projected to become more variable over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*). The average annual global land precipitation is projected to increase by 0–5% under the very low GHG emissions scenario (SSP1-1.9), 1.5–8% for the intermediate GHG emissions scenario (SSP2-4.5) and 1–13% under the very high GHG emissions scenario (SSP5-8.5) by 2081–2100 relative to 1995–2014 (*likely* ranges). Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and limited areas in the tropics in SSP2-4.5, SSP3-7.0 and SSP5-8.5 (*very likely*). The portion of the global land experiencing detectable increases or decreases in seasonal mean precipitation is projected to increase (*medium confidence*). There is *high confidence* in an earlier onset of spring snowmelt, with higher peak flows at the expense of summer flows in snow-dominated regions globally.

{4.3, 4.5, 4.6, 8.2, 8.4, Atlas.3, TS.2.6, TS.4.3, Box TS.6} (Figure SPM.5)

B.3.2 A warmer climate will intensify very wet and very dry weather and climate events and seasons, with implications for flooding or drought (*high confidence*), but the location and frequency of these events depend on projected changes in regional atmospheric circulation, including monsoons and mid-latitude storm tracks. It is *very likely* that rainfall variability related to the El Niño–Southern Oscillation is projected to be amplified by the second half of the 21st century in the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios.

{4.3, 4.5, 4.6, 8.2, 8.4, 8.5, 11.4, 11.6, 11.9, 12.4, TS.2.6, TS.4.2, Box TS.6} (Figure SPM.5, Figure SPM.6)

B.3.3 Monsoon precipitation is projected to increase in the mid- to long term at the global scale, particularly over South and South East Asia, East Asia and West Africa apart from the far west Sahel (*high confidence*). The monsoon season is projected to have a delayed onset over North and South America and West Africa (*high confidence*) and a delayed retreat over West Africa (*medium confidence*).

{4.4, 4.5, 8.2, 8.3, 8.4, Box 8.2, Box TS.13}

B.3.4 A projected southward shift and intensification of Southern Hemisphere summer mid-latitude storm tracks and associated precipitation is *likely* in the long term under high GHG emissions scenarios (SSP3-7.0, SSP5-8.5), but in the near term the effect of stratospheric ozone recovery counteracts these changes (*high confidence*). There is *medium confidence* in a continued poleward shift of storms and their precipitation in the North Pacific, while there is *low confidence* in projected changes in the North Atlantic storm tracks.

{4.4, 4.5, 8.4, TS.2.3, TS.4.2}

B.4 Under scenarios with increasing CO₂ emissions, the ocean and land carbon sinks are projected to be less effective at slowing the accumulation of CO₂ in the atmosphere.

{4.3, 5.2, 5.4, 5.5, 5.6} (Figure SPM.7)

- B.4.1** While natural land and ocean carbon sinks are projected to take up, in absolute terms, a progressively larger amount of CO₂ under higher compared to lower CO₂ emissions scenarios, they become less effective, that is, the proportion of emissions taken up by land and ocean decrease with increasing cumulative CO₂ emissions. This is projected to result in a higher proportion of emitted CO₂ remaining in the atmosphere (*high confidence*). {5.2, 5.4, Box TS.5} (Figure SPM.7)
- B.4.2** Based on model projections, under the intermediate GHG emissions scenario that stabilizes atmospheric CO₂ concentrations this century (SSP2-4.5), the rates of CO₂ taken up by the land and ocean are projected to decrease in the second half of the 21st century (*high confidence*). Under the very low and low GHG emissions scenarios (SSP1-1.9, SSP1-2.6), where CO₂ concentrations peak and decline during the 21st century, the land and ocean begin to take up less carbon in response to declining atmospheric CO₂ concentrations (*high confidence*) and turn into a weak net source by 2100 under SSP1-1.9 (*medium confidence*). It is *very unlikely* that the combined global land and ocean sink will turn into a source by 2100 under scenarios without net negative emissions (SSP2-4.5, SSP3-7.0, SSP5-8.5).³² {4.3, 5.4, 5.5, 5.6, Box TS.5, TS.3.3}
- B.4.3** The magnitude of feedbacks between climate change and the carbon cycle becomes larger but also more uncertain in high CO₂ emissions scenarios (*very high confidence*). However, climate model projections show that the uncertainties in atmospheric CO₂ concentrations by 2100 are dominated by the differences between emissions scenarios (*high confidence*). Additional ecosystem responses to warming not yet fully included in climate models, such as CO₂ and CH₄ fluxes from wetlands, permafrost thaw and wildfires, would further increase concentrations of these gases in the atmosphere (*high confidence*). {5.4, Box TS.5, TS.3.2}

The proportion of CO₂ emissions taken up by land and ocean carbon sinks is smaller in scenarios with higher cumulative CO₂ emissions

Total cumulative CO₂ emissions **taken up by land and ocean** (colours) and remaining in the atmosphere (grey) under the five illustrative scenarios from 1850 to 2100

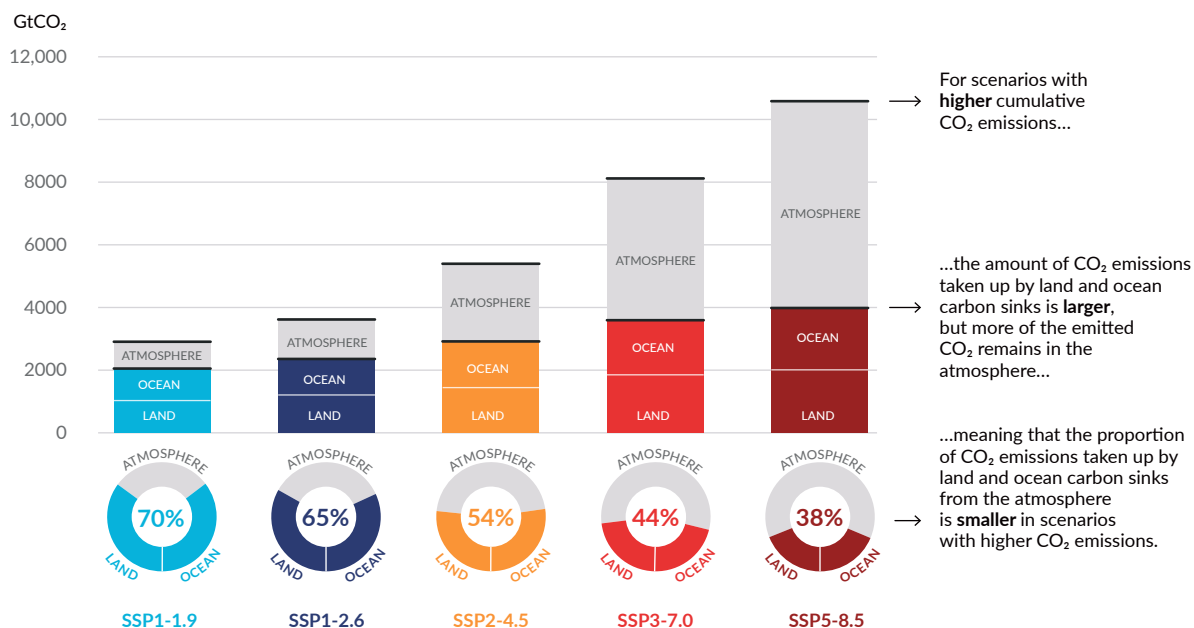


Figure SPM.7 | Cumulative anthropogenic CO₂ emissions taken up by land and ocean sinks by 2100 under the five illustrative scenarios

The cumulative anthropogenic (human-caused) carbon dioxide (CO₂) emissions taken up by the land and ocean sinks under the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are simulated from 1850 to 2100 by Coupled Model Intercomparison Project Phase 6 (CMIP6) climate models in the concentration-driven simulations. Land and ocean carbon sinks respond to past, current and future emissions; therefore, cumulative sinks from 1850 to 2100 are presented here. During the historical period (1850–2019) the observed land and ocean sink took up 1430 GtCO₂ (59% of the emissions).

³² These projected adjustments of carbon sinks to stabilization or decline of atmospheric CO₂ are accounted for in calculations of remaining carbon budgets.

The bar chart illustrates the projected amount of cumulative anthropogenic CO₂ emissions (GtCO₂) between 1850 and 2100 remaining in the atmosphere (grey part) and taken up by the land and ocean (coloured part) in the year 2100. **The doughnut chart** illustrates the proportion of the cumulative anthropogenic CO₂ emissions taken up by the land and ocean sinks and remaining in the atmosphere in the year 2100. Values in % indicate the proportion of the cumulative anthropogenic CO₂ emissions taken up by the combined land and ocean sinks in the year 2100. The overall anthropogenic carbon emissions are calculated by adding the net global land-use emissions from the CMIP6 scenario database to the other sectoral emissions calculated from climate model runs with prescribed CO₂ concentrations.³³ Land and ocean CO₂ uptake since 1850 is calculated from the net biome productivity on land, corrected for CO₂ losses due to land-use change by adding the land-use change emissions, and net ocean CO₂ flux.

{5.2.1; Table 5.1; 5.4.5; Figure 5.25; Box TS.5; Box TS.5, Figure 1}

B.5 Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.

{2.3, Cross-Chapter Box 2.4, 4.3, 4.5, 4.7, 5.3, 9.2, 9.4, 9.5, 9.6, Box 9.4} (Figure SPM.8)

- B.5.1** Past GHG emissions since 1750 have committed the global ocean to future warming (*high confidence*). Over the rest of the 21st century, *likely* ocean warming ranges from 2–4 (SSP1-2.6) to 4–8 times (SSP5-8.5) the 1971–2018 change. Based on multiple lines of evidence, upper ocean stratification (*virtually certain*), ocean acidification (*virtually certain*) and ocean deoxygenation (*high confidence*) will continue to increase in the 21st century, at rates dependent on future emissions. Changes are irreversible on centennial to millennial time scales in global ocean temperature (*very high confidence*), deep-ocean acidification (*very high confidence*) and deoxygenation (*medium confidence*). {4.3, 4.5, 4.7, 5.3, 9.2, TS.2.4} (Figure SPM.8)
- B.5.2** Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*). Loss of permafrost carbon following permafrost thaw is irreversible at centennial time scales (*high confidence*). Continued ice loss over the 21st century is *virtually certain* for the Greenland Ice Sheet and *likely* for the Antarctic Ice Sheet. There is *high confidence* that total ice loss from the Greenland Ice Sheet will increase with cumulative emissions. There is *limited evidence* for low-likelihood, high-impact outcomes (resulting from ice-sheet instability processes characterized by deep uncertainty and in some cases involving tipping points) that would strongly increase ice loss from the Antarctic Ice Sheet for centuries under high GHG emissions scenarios.³⁴ {4.3, 4.7, 5.4, 9.4, 9.5, Box 9.4, Box TS.1, TS.2.5}
- B.5.3** It is *virtually certain* that global mean sea level will continue to rise over the 21st century. Relative to 1995–2014, the *likely* global mean sea level rise by 2100 is 0.28–0.55 m under the very low GHG emissions scenario (SSP1-1.9); 0.32–0.62 m under the low GHG emissions scenario (SSP1-2.6); 0.44–0.76 m under the intermediate GHG emissions scenario (SSP2-4.5); and 0.63–1.01 m under the very high GHG emissions scenario (SSP5-8.5); and by 2150 is 0.37–0.86 m under the very low scenario (SSP1-1.9); 0.46–0.99 m under the low scenario (SSP1-2.6); 0.66–1.33 m under the intermediate scenario (SSP2-4.5); and 0.98–1.88 m under the very high scenario (SSP5-8.5) (*medium confidence*).³⁵ Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and 5 m by 2150 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice-sheet processes. {4.3, 9.6, Box 9.4, Box TS.4} (Figure SPM.8)
- B.5.4** In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep-ocean warming and ice-sheet melt and will remain elevated for thousands of years (*high confidence*). Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C, 2 to 6 m if limited to 2°C and 19 to 22 m with 5°C of warming, and it will continue to rise over subsequent millennia (*low confidence*). Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: *likely* 5–10 m higher than today around 125,000 years ago, when global temperatures were *very likely* 0.5°C–1.5°C higher than 1850–1900; and *very likely* 5–25 m higher roughly 3 million years ago, when global temperatures were 2.5°C–4°C higher (*medium confidence*). {2.3, Cross-Chapter Box 2.4, 9.6, Box TS.2, Box TS.4, Box TS.9}

33 The other sectoral emissions are calculated as the residual of the net land and ocean CO₂ uptake and the prescribed atmospheric CO₂ concentration changes in the CMIP6 simulations. These calculated emissions are net emissions and do not separate gross anthropogenic emissions from removals, which are included implicitly.

34 Low-likelihood, high-impact outcomes are those whose probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high. A tipping point is a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly. (Glossary) {1.4, Cross-Chapter Box 1.3, 4.7}

35 To compare to the 1986–2005 baseline period used in AR5 and SROCC, add 0.03 m to the global mean sea level rise estimates. To compare to the 1900 baseline period used in Figure SPM.8, add 0.16 m.

Human activities affect all the major climate system components, with some responding over decades and others over centuries

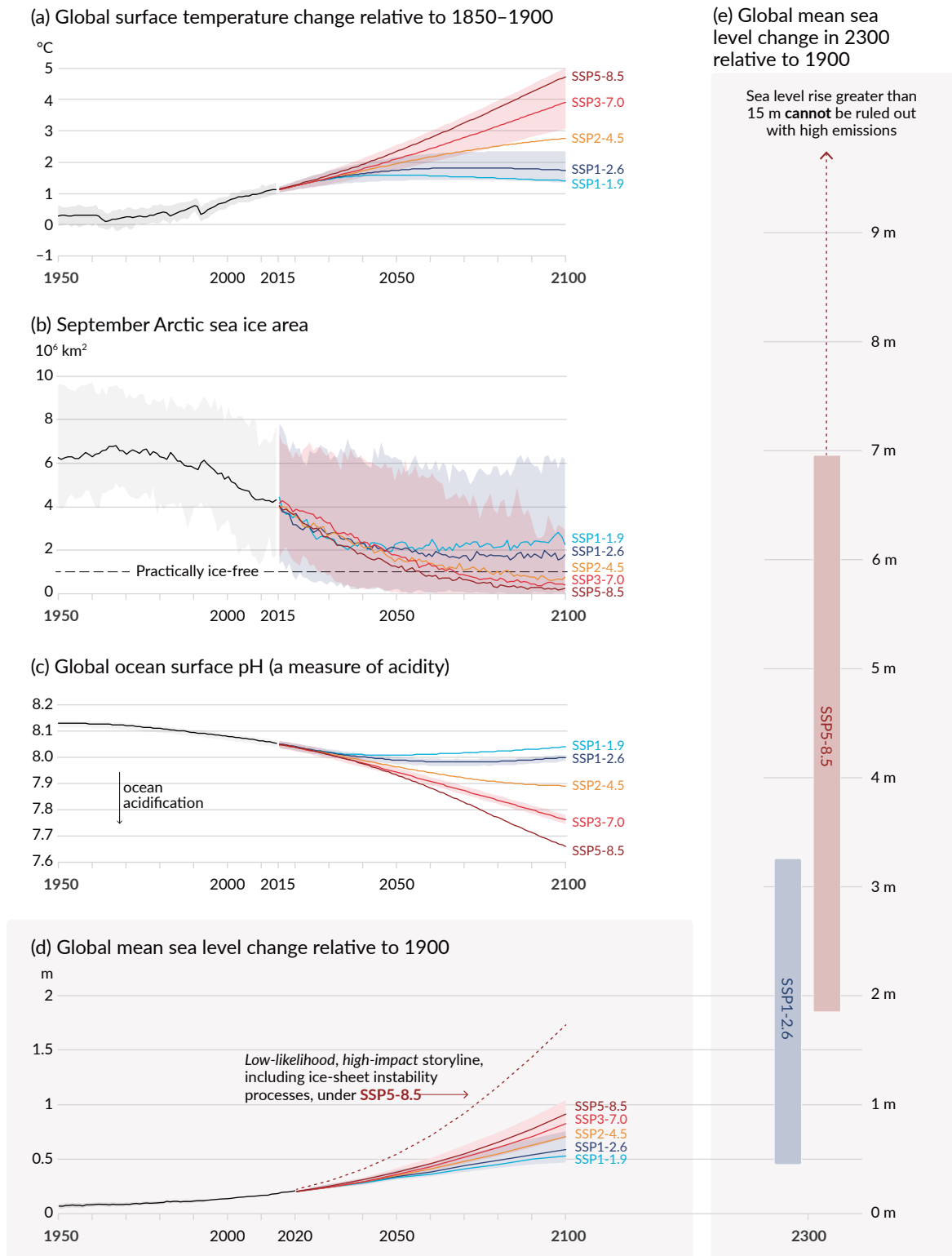


Figure SPM.8 | Selected indicators of global climate change under the five illustrative scenarios used in this Report

The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges – more detail is provided for each panel below. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

Panel (a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining Coupled Model Intercomparison Project Phase 6 (CMIP6) model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (see Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel (b) September Arctic sea ice area in 10⁶ km² based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. The Arctic is projected to be practically ice-free near mid-century under intermediate and high GHG emissions scenarios.

Panel (c) Global ocean surface pH (a measure of acidity) based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel (d) Global mean sea level change in metres, relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice-sheet, and glacier models. *Likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Only *likely* ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out; because of *low confidence* in projections of these processes, this curve does not constitute part of a *likely* range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014.

Panel (e) Global mean sea level change at 2300 in metres relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice-sheet processes that cannot be ruled out.

Panels (b) and (c) are based on single simulations from each model, and so include a component of internal variability. Panels (a), (d) and (e) are based on long-term averages, and hence the contributions from internal variability are small.

{4.3; Figures 4.2, 4.8, and 4.11; 9.6; Figure 9.27; Figures TS.8 and TS.11; Box TS.4, Figure 1}

C. Climate Information for Risk Assessment and Regional Adaptation

Physical climate information addresses how the climate system responds to the interplay between human influence, natural drivers and internal variability. Knowledge of the climate response and the range of possible outcomes, including low-likelihood, high impact outcomes, informs climate services, the assessment of climate-related risks, and adaptation planning. Physical climate information at global, regional and local scales is developed from multiple lines of evidence, including observational products, climate model outputs and tailored diagnostics.

C.1 Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.

{1.4, 2.2, 3.3, Cross-Chapter Box 3.1, 4.4, 4.6, Cross-Chapter Box 4.1, Box 7.2, 8.3, 8.5, 9.2, 10.3, 10.4, 10.6, 11.3, 12.5, Atlas.4, Atlas.5, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box Atlas.2}

C.1.1 The historical global surface temperature record highlights that decadal variability has both enhanced and masked underlying human-caused long-term changes, and this variability will continue into the future (*very high confidence*). For example, internal decadal variability and variations in solar and volcanic drivers partially masked human-caused surface global warming during 1998–2012, with pronounced regional and seasonal signatures (*high confidence*). Nonetheless, the heating of the climate system continued during this period, as reflected in both the continued warming of the global ocean (*very high confidence*) and in the continued rise of hot extremes over land (*medium confidence*).

{1.4, 3.3, Cross-Chapter Box 3.1, 4.4, Box 7.2, 9.2, 11.3, Cross-Section Box TS.1} (Figure SPM.1)

C.1.2 Projected human-caused changes in mean climate and climatic impact-drivers (CIDs),³⁶ including extremes, will be either amplified or attenuated by internal variability (*high confidence*).³⁷ Near-term cooling at any particular location with respect to present climate could occur and would be consistent with the global surface temperature increase due to human influence (*high confidence*).

{1.4, 4.4, 4.6, 10.4, 11.3, 12.5, Atlas.5, Atlas.10, Atlas.11, TS.4.2}

36 Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions (Glossary). CID types include heat and cold, wet and dry, wind, snow and ice, coastal and open ocean.

37 The main internal variability phenomena include El Niño–Southern Oscillation, Pacific Decadal Variability and Atlantic Multi-decadal Variability through their regional influence.

- C.1.3** Internal variability has largely been responsible for the amplification and attenuation of the observed human-caused decadal-to-multi-decadal mean precipitation changes in many land regions (*high confidence*). At global and regional scales, near-term changes in monsoons will be dominated by the effects of internal variability (*medium confidence*). In addition to the influence of internal variability, near-term projected changes in precipitation at global and regional scales are uncertain because of model uncertainty and uncertainty in forcings from natural and anthropogenic aerosols (*medium confidence*). {1.4, 4.4, 8.3, 8.5, 10.3, 10.4, 10.5, 10.6, Atlas.4, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box Atlas.2, TS.4.2, Box TS.6, Box TS.13}
- C.1.4** Based on paleoclimate and historical evidence, it is *likely* that at least one large explosive volcanic eruption would occur during the 21st century.³⁸ Such an eruption would reduce global surface temperature and precipitation, especially over land, for one to three years, alter the global monsoon circulation, modify extreme precipitation and change many CIDs (*medium confidence*). If such an eruption occurs, this would therefore temporarily and partially mask human-caused climate change. {2.2, 4.4, Cross-Chapter Box 4.1, 8.5, TS.2.1}
- C.2** **With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.** {8.2, 9.3, 9.5, 9.6, Box 10.3, 11.3, 11.4, 11.5, 11.6, 11.7, 11.9, Box 11.3, Box 11.4, Cross-Chapter Box 11.1, 12.2, 12.3, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11} (Table SPM.1, Figure SPM.9)
- C.2.1** All regions³⁹ are projected to experience further increases in hot climatic impact-drivers (CIDs) and decreases in cold CIDs (*high confidence*). Further decreases are projected in permafrost; snow, glaciers and ice sheets; and lake and Arctic sea ice (*medium to high confidence*).⁴⁰ These changes would be larger at 2°C global warming or above than at 1.5°C (*high confidence*). For example, extreme heat thresholds relevant to agriculture and health are projected to be exceeded more frequently at higher global warming levels (*high confidence*). {9.3, 9.5, 11.3, 11.9, Cross-Chapter Box 11.1, 12.3, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3} (Table SPM.1, Figure SPM.9)
- C.2.2** At 1.5°C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in most regions in Africa and Asia (*high confidence*), North America (*medium to high confidence*)⁴⁰ and Europe (*medium confidence*). Also, more frequent and/or severe agricultural and ecological droughts are projected in a few regions in all inhabited continents except Asia compared to 1850–1900 (*medium confidence*); increases in meteorological droughts are also projected in a few regions (*medium confidence*). A small number of regions are projected to experience increases or decreases in mean precipitation (*medium confidence*). {11.4, 11.5, 11.6, 11.9, Atlas.4, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3} (Table SPM.1)
- C.2.3** At 2°C global warming and above, the level of confidence in and the magnitude of the change in droughts and heavy and mean precipitation increase compared to those at 1.5°C. Heavy precipitation and associated flooding events are projected to become more intense and frequent in the Pacific Islands and across many regions of North America and Europe (*medium to high confidence*).⁴⁰ These changes are also seen in some regions in Australasia and Central and South America (*medium confidence*). Several regions in Africa, South America and Europe are projected to experience an increase in frequency and/or severity of agricultural and ecological droughts with *medium to high confidence*;⁴⁰ increases are also projected in Australasia, Central and North America, and the Caribbean with *medium confidence*. A small number of regions in Africa, Australasia, Europe and North America are also projected to be affected by increases in hydrological droughts, and several regions are projected to be affected by increases or decreases in meteorological droughts, with more regions displaying an increase (*medium confidence*). Mean precipitation is projected to increase in all polar, northern European and northern North American regions, most Asian regions and two regions of South America (*high confidence*). {11.4, 11.6, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.11, TS.4.3} (Table SPM.1, Figure SPM.5, Figure SPM.6, Figure SPM.9)

38 Based on 2500 year reconstructions, eruptions more negative than -1 W m^{-2} occur on average twice per century.

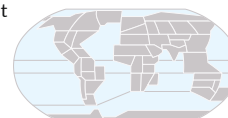
39 Regions here refer to the AR6 WGI reference regions used in this Report to summarize information in sub-continental and oceanic regions. Changes are compared to averages over the last 20–40 years unless otherwise specified. {1.4, 12.4, Atlas.1}.

40 The specific level of confidence or likelihood depends on the region considered. Details can be found in the Technical Summary and the underlying Report.

- C.2.4 More CIDs across more regions are projected to change at 2°C and above compared to 1.5°C global warming (*high confidence*). Region-specific changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), increases in river floods (*medium to high confidence*),⁴⁰ reductions in mean precipitation and increases in aridity (*medium to high confidence*),⁴⁰ and increases in fire weather (*medium to high confidence*).⁴⁰ There is *low confidence* in most regions in potential future changes in other CIDs, such as hail, ice storms, severe storms, dust storms, heavy snowfall and landslides.
{11.7, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.6, Atlas.7, Atlas.8, Atlas.10, TS.4.3.1, TS.4.3.2, TS.5} (Table SPM.1, Figure SPM.9)
- C.2.5 It is *very likely to virtually certain*⁴⁰ that regional mean relative sea level rise will continue throughout the 21st century, except in a few regions with substantial geologic land uplift rates. Approximately two-thirds of the global coastline has a projected regional relative sea level rise within $\pm 20\%$ of the global mean increase (*medium confidence*). Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100 (*high confidence*). Relative sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts (*high confidence*).
{9.6, 12.4, 12.5, Cross-Chapter Box 12.1, Box TS.4, TS.4.3} (Figure SPM.9)
- C.2.6 Cities intensify human-induced warming locally, and further urbanization together with more frequent hot extremes will increase the severity of heatwaves (*very high confidence*). Urbanization also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). In coastal cities, the combination of more frequent extreme sea level events (due to sea level rise and storm surge) and extreme rainfall/riverflow events will make flooding more probable (*high confidence*).
{8.2, Box 10.3, 11.3, 12.4, Box TS.14}
- C.2.7 Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*). In particular, concurrent heatwaves and droughts are *likely* to become more frequent. Concurrent extremes at multiple locations, including in crop-producing areas, become more frequent at 2°C and above compared to 1.5°C global warming (*high confidence*).
{11.8, Box 11.3, Box 11.4, 12.3, 12.4, Cross-Chapter Box 12.1, TS.4.3} (Table SPM.1)

Multiple climatic impact-drivers are projected to change in all regions of the world

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. The CIDs are grouped into seven types, which are summarized under the icons in the figure. All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in at least 15 CIDs. For many CID changes, there is wide geographical variation, and so each region is projected to experience a specific set of CID changes. Each bar in the chart represents a specific geographical set of changes that can be explored in the WGI Interactive Atlas.



interactive-atlas.ipcc.ch

Number of land & coastal regions (a) and open-ocean regions (b) where each climatic impact-driver (CID) is projected to increase or decrease with high confidence (dark shade) or medium confidence (light shade)

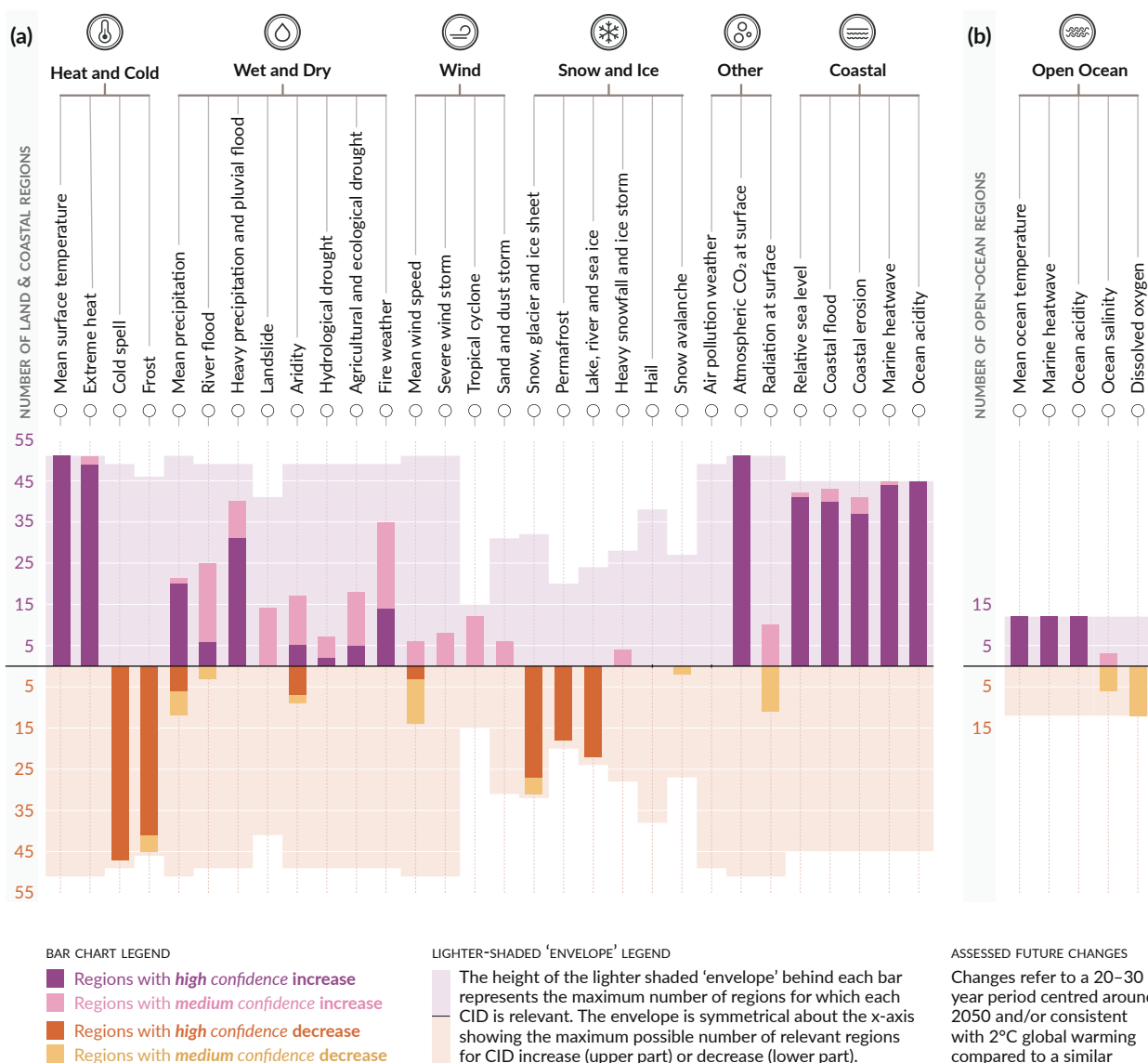


Figure SPM.9 | Synthesis of the number of AR6 WGI reference regions where climatic impact-drivers are projected to change

A total of 35 climatic impact-drivers (CIDs) grouped into seven types are shown: heat and cold; wet and dry; wind; snow and ice; coastal; open ocean; and other. For each CID, the bar in the graph below displays the number of AR6 WGI reference regions where it is projected to change. The **colours** represent the direction of change and the level of confidence in the change: purple indicates an increase while brown indicates a decrease; darker and lighter shades refer to **high** and **medium confidence**, respectively. Lighter background colours represent the maximum number of regions for which each CID is broadly relevant.

Panel (a) shows the 30 CIDs relevant to the **land and coastal regions**, while **panel (b)** shows the five CIDs relevant to the **open-ocean regions**. Marine heatwaves and ocean acidity are assessed for coastal ocean regions in panel (a) and for open-ocean regions in panel (b). Changes refer to a 20–30-year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960–2014, except for hydrological drought and agricultural and ecological drought, which is compared to 1850–1900. Definitions of the regions are provided in Sections 12.4 and Atlas.1 and the Interactive Atlas (see <https://interactive-atlas.ipcc.ch/>).

[11.9, 12.2, 12.4, Atlas.1, Table TS.5, Figures TS.22 and TS.25] (Table SPM.1)

- C.3 Low-likelihood outcomes, such as ice-sheet collapse, abrupt ocean circulation changes, some compound extreme events, and warming substantially larger than the assessed *very likely* range of future warming, cannot be ruled out and are part of risk assessment.**
{1.4, Cross-Chapter Box 1.3, 4.3, 4.4, 4.8, Cross-Chapter Box 4.1, 8.6, 9.2, Box 9.4, 11.8, Box 11.2, Cross-Chapter Box 12.1} (Table SPM.1)
- C.3.1 If global warming exceeds the assessed *very likely* range for a given GHG emissions scenario, including low GHG emissions scenarios, global and regional changes in many aspects of the climate system, such as regional precipitation and other CIDs, would also exceed their assessed *very likely* ranges (*high confidence*). Such low-likelihood, high-warming outcomes are associated with potentially very large impacts, such as through more intense and more frequent heatwaves and heavy precipitation, and high risks for human and ecological systems, particularly for high GHG emissions scenarios.
{Cross-Chapter Box 1.3, 4.3, 4.4, 4.8, Box 9.4, Box 11.2, Cross-Chapter Box 12.1, TS.1.4, Box TS.3, Box TS.4} (Table SPM.1)
- C.3.2 Low-likelihood, high-impact outcomes³⁴ could occur at global and regional scales even for global warming within the *very likely* range for a given GHG emissions scenario. The probability of low-likelihood, high-impact outcomes increases with higher global warming levels (*high confidence*). Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice-sheet melt and forest dieback, cannot be ruled out (*high confidence*).
{1.4, 4.3, 4.4, 4.8, 5.4, 8.6, Box 9.4, Cross-Chapter Box 12.1, TS.1.4, TS.2.5, Box TS.3, Box TS.4, Box TS.9} (Table SPM.1)
- C.3.3 If global warming increases, some compound extreme events¹⁸ with low likelihood in past and current climate will become more frequent, and there will be a higher likelihood that events with increased intensities, durations and/or spatial extents unprecedented in the observational record will occur (*high confidence*).
{11.8, Box 11.2, Cross-Chapter Box 12.1, Box TS.3, Box TS.9}
- C.3.4 The Atlantic Meridional Overturning Circulation is *very likely* to weaken over the 21st century for all emissions scenarios. While there is *high confidence* in the 21st century decline, there is only *low confidence* in the magnitude of the trend. There is *medium confidence* that there will not be an abrupt collapse before 2100. If such a collapse were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle, such as a southward shift in the tropical rain belt, weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons, and drying in Europe.
{4.3, 8.6, 9.2, TS.2.4, Box TS.3}
- C.3.5 Unpredictable and rare natural events not related to human influence on climate may lead to low-likelihood, high-impact outcomes. For example, a sequence of large explosive volcanic eruptions within decades has occurred in the past, causing substantial global and regional climate perturbations over several decades. Such events cannot be ruled out in the future, but due to their inherent unpredictability they are not included in the illustrative set of scenarios referred to in this Report {2.2, Cross-Chapter Box 4.1, Box TS.3} (Box SPM.1)

D. Limiting Future Climate Change

Since AR5, estimates of remaining carbon budgets have been improved by a new methodology first presented in SR1.5, updated evidence, and the integration of results from multiple lines of evidence. A comprehensive range of possible future air pollution controls in scenarios is used to consistently assess the effects of various assumptions on projections of climate and air pollution. A novel development is the ability to ascertain when climate responses to emissions reductions would become discernible above natural climate variability, including internal variability and responses to natural drivers.

- D.1 From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO₂ emissions, reaching at least net zero CO₂ emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH₄ emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.**
{3.3, 4.6, 5.1, 5.2, 5.4, 5.5, 5.6, Box 5.2, Cross-Chapter Box 5.1, 6.7, 7.6, 9.6} (Figure SPM.10, Table SPM.2)

D.1.1 This Report reaffirms with *high confidence* the AR5 finding that there is a near-linear relationship between cumulative anthropogenic CO₂ emissions and the global warming they cause. Each 1000 GtCO₂ of cumulative CO₂ emissions is assessed to *likely* cause a 0.27°C to 0.63°C increase in global surface temperature with a best estimate of 0.45°C.⁴¹ This is a narrower range compared to AR5 and SR1.5. This quantity is referred to as the transient climate response to cumulative CO₂ emissions (TCRE). This relationship implies that reaching net zero anthropogenic CO₂ emissions⁴² is a requirement to stabilize human-induced global temperature increase at any level, but that limiting global temperature increase to a specific level would imply limiting cumulative CO₂ emissions to within a carbon budget.⁴³ {5.4, 5.5, TS.1.3, TS.3.3, Box TS.5} (Figure SPM.10)

Every tonne of CO₂ emissions adds to global warming

Global surface temperature increase since 1850–1900 (°C) as a function of cumulative CO₂ emissions (GtCO₂)

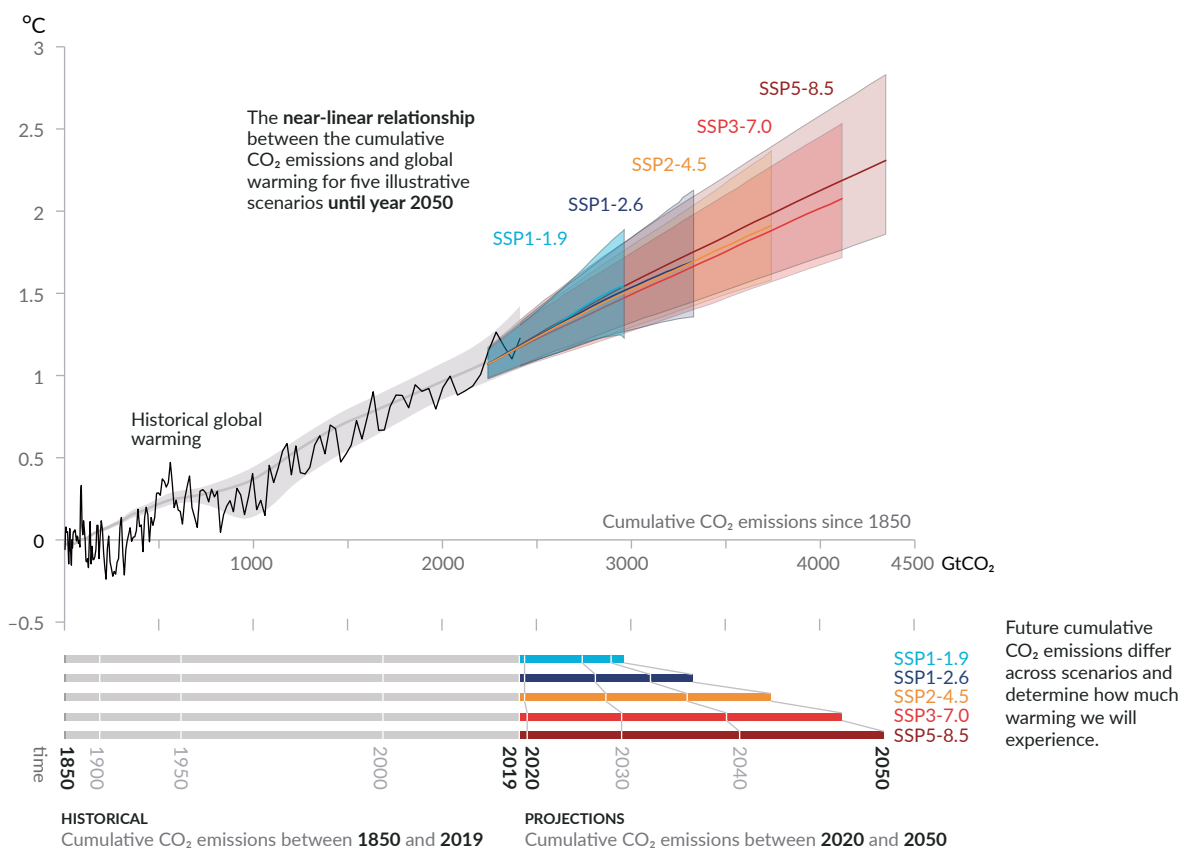


Figure SPM.10 | Near-linear relationship between cumulative CO₂ emissions and the increase in global surface temperature

Top panel: Historical data (thin black line) shows observed global surface temperature increase in °C since 1850–1900 as a function of historical cumulative carbon dioxide (CO₂) emissions in GtCO₂ from 1850 to 2019. The grey range with its central line shows a corresponding estimate of the historical human-caused surface warming (see Figure SPM.2). Coloured areas show the assessed *very likely* range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative CO₂ emissions from 2020 until year 2050 for the set of illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5; see Figure SPM.4). Projections use the cumulative CO₂ emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcings. The relationship is illustrated over the domain of cumulative CO₂ emissions for which there is *high confidence* that the transient climate response to cumulative CO₂ emissions (TCRE) remains constant, and for the time period from 1850 to 2050 over which global CO₂ emissions remain net positive under all illustrative scenarios, as there is *limited evidence* supporting the quantitative application of TCRE to estimate temperature evolution under net negative CO₂ emissions.

Bottom panel: Historical and projected cumulative CO₂ emissions in GtCO₂ for the respective scenarios.

{Section 5.5, Figure 5.31, Figure TS.18}

⁴¹ In the literature, units of °C per 1000 PgC (petagrams of carbon) are used, and the AR6 reports the TCRE *likely* range as 1.0°C to 2.3°C per 1000 PgC in the underlying report, with a best estimate of 1.65°C.

⁴² The condition in which anthropogenic carbon dioxide (CO₂) emissions are balanced by anthropogenic CO₂ removals over a specified period (Glossary).

⁴³ The term 'carbon budget' refers to the maximum amount of cumulative net global anthropogenic CO₂ emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcings. This is referred to as the total carbon budget when expressed starting from the pre-industrial period, and as the remaining carbon budget when expressed from a recent specified date (Glossary). Historical cumulative CO₂ emissions determine to a large degree warming to date, while future emissions cause future additional warming. The remaining carbon budget indicates how much CO₂ could still be emitted while keeping warming below a specific temperature level.

- D.1.2 Over the period 1850–2019, a total of 2390 ± 240 (*likely* range) GtCO₂ of anthropogenic CO₂ was emitted. Remaining carbon budgets have been estimated for several global temperature limits and various levels of probability, based on the estimated value of TCRE and its uncertainty, estimates of historical warming, variations in projected warming from non-CO₂ emissions, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO₂ emissions reach net zero. {5.1, 5.5, Box 5.2, TS.3.3} (Table SPM.2)

Table SPM.2 | Estimates of historical carbon dioxide (CO₂) emissions and remaining carbon budgets. Estimated remaining carbon budgets are calculated from the beginning of 2020 and extend until global net zero CO₂ emissions are reached. They refer to CO₂ emissions, while accounting for the global warming effect of non-CO₂ emissions. Global warming in this table refers to human-induced global surface temperature increase, which excludes the impact of natural variability on global temperatures in individual years. (Table 3.1, 5.5.1, 5.5.2, Box 5.2, Table 5.1, Table 5.7, Table 5.8, Table TS.3)

Global Warming Between 1850–1900 and 2010–2019 (°C)		Historical Cumulative CO ₂ Emissions from 1850 to 2019 (GtCO ₂)				
1.07 (0.8–1.3; likely range)		2390 (± 240 ; likely range)				
Approximate global warming relative to 1850–1900 until temperature limit (°C) ^a	Additional global warming relative to 2010–2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 (GtCO ₂)				
		Likelihood of limiting global warming to temperature limit ^b				
		17%	33%	50%	67%	83%
1.5	0.43	900	650	500	400	300
1.7	0.63	1450	1050	850	700	550
2.0	0.93	2300	1700	1350	1150	900

^a Values at each 0.1°C increment of warming are available in Tables TS.3 and 5.8.

^b This likelihood is based on the uncertainty in transient climate response to cumulative CO₂ emissions (TCRE) and additional Earth system feedbacks and provides the probability that global warming will not exceed the temperature levels provided in the two left columns. Uncertainties related to historical warming (± 550 GtCO₂) and non-CO₂ forcing and response (± 220 GtCO₂) are partially addressed by the assessed uncertainty in TCRE, but uncertainties in recent emissions since 2015 (± 20 GtCO₂) and the climate response after net zero CO₂ emissions are reached (± 420 GtCO₂) are separate.

^c Remaining carbon budget estimates consider the warming from non-CO₂ drivers as implied by the scenarios assessed in SR1.5. The Working Group III Contribution to AR6 will assess mitigation of non-CO₂ emissions.

- D.1.3 Several factors that determine estimates of the remaining carbon budget have been re-assessed, and updates to these factors since SR1.5 are small. When adjusted for emissions since previous reports, estimates of remaining carbon budgets are therefore of similar magnitude compared to SR1.5 but larger compared to AR5 due to methodological improvements.⁴⁴ {5.5, Box 5.2, TS.3.3} (Table SPM.2)
- D.1.4 Anthropogenic CO₂ removal (CDR) has the potential to remove CO₂ from the atmosphere and durably store it in reservoirs (*high confidence*). CDR aims to compensate for residual emissions to reach net zero CO₂ or net zero GHG emissions or, if implemented at a scale where anthropogenic removals exceed anthropogenic emissions, to lower surface temperature. CDR methods can have potentially wide-ranging effects on biogeochemical cycles and climate, which can either weaken or strengthen the potential of these methods to remove CO₂ and reduce warming, and can also influence water availability and quality, food production and biodiversity⁴⁵ (*high confidence*). {5.6, Cross-Chapter Box 5.1, TS.3.3}
- D.1.5 Anthropogenic CO₂ removal (CDR) leading to global net negative emissions would lower the atmospheric CO₂ concentration and reverse surface ocean acidification (*high confidence*). Anthropogenic CO₂ removals and emissions are partially

⁴⁴ Compared to AR5, and when taking into account emissions since AR5, estimates in AR6 are about 300–350 GtCO₂ larger for the remaining carbon budget consistent with limiting warming to 1.5°C; for 2°C, the difference is about 400–500 GtCO₂.

⁴⁵ Potential negative and positive effects of CDR for biodiversity, water and food production are methods-specific and are often highly dependent on local context, management, prior land use, and scale. IPCC Working Groups II and III assess the CDR potential and ecological and socio-economic effects of CDR methods in their AR6 contributions.

compensated by CO₂ release and uptake respectively, from or to land and ocean carbon pools (*very high confidence*). CDR would lower atmospheric CO₂ by an amount approximately equal to the increase from an anthropogenic emission of the same magnitude (*high confidence*). The atmospheric CO₂ decrease from anthropogenic CO₂ removals could be up to 10% less than the atmospheric CO₂ increase from an equal amount of CO₂ emissions, depending on the total amount of CDR (*medium confidence*).
{5.3, 5.6, TS.3.3}

- D.1.6 If global net negative CO₂ emissions were to be achieved and be sustained, the global CO₂-induced surface temperature increase would be gradually reversed but other climate changes would continue in their current direction for decades to millennia (*high confidence*). For instance, it would take several centuries to millennia for global mean sea level to reverse course even under large net negative CO₂ emissions (*high confidence*).
{4.6, 9.6, TS.3.3}
- D.1.7 In the five illustrative scenarios, simultaneous changes in CH₄, aerosol and ozone precursor emissions, which also contribute to air pollution, lead to a net global surface warming in the near and long term (*high confidence*). In the long term, this net warming is lower in scenarios assuming air pollution controls combined with strong and sustained CH₄ emissions reductions (*high confidence*). In the low and very low GHG emissions scenarios, assumed reductions in anthropogenic aerosol emissions lead to a net warming, while reductions in CH₄ and other ozone precursor emissions lead to a net cooling. Because of the short lifetime of both CH₄ and aerosols, these climate effects partially counterbalance each other, and reductions in CH₄ emissions also contribute to improved air quality by reducing global surface ozone (*high confidence*).
{6.7, Box TS.7} (Figure SPM.2, Box SPM.1)
- D.1.8 Achieving global net zero CO₂ emissions, with anthropogenic CO₂ emissions balanced by anthropogenic removals of CO₂, is a requirement for stabilizing CO₂-induced global surface temperature increase. This is different from achieving net zero GHG emissions, where metric-weighted anthropogenic GHG emissions equal metric-weighted anthropogenic GHG removals. For a given GHG emissions pathway, the pathways of individual GHGs determine the resulting climate response,⁴⁶ whereas the choice of emissions metric⁴⁷ used to calculate aggregated emissions and removals of different GHGs affects what point in time the aggregated GHGs are calculated to be net zero. Emissions pathways that reach and sustain net zero GHG emissions defined by the 100-year global warming potential are projected to result in a decline in surface temperature after an earlier peak (*high confidence*).
{4.6, 7.6, Box 7.3, TS.3.3}
- D.2 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) lead within years to discernible effects on greenhouse gas and aerosol concentrations and air quality, relative to high and very high GHG emissions scenarios (SSP3-7.0 or SSP5-8.5). Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers (*high confidence*).**
{4.6, 6.6, 6.7, Cross-Chapter Box 6.1, 9.6, 11.2, 11.4, 11.5, 11.6, Cross-Chapter Box 11.1, 12.4, 12.5} (Figure SPM.8, Figure SPM.10)
- D.2.1 Emissions reductions in 2020 associated with measures to reduce the spread of COVID-19 led to temporary but detectable effects on air pollution (*high confidence*) and an associated small, temporary increase in total radiative forcing, primarily due to reductions in cooling caused by aerosols arising from human activities (*medium confidence*). Global and regional climate responses to this temporary forcing are, however, undetectable above natural variability (*high confidence*). Atmospheric CO₂ concentrations continued to rise in 2020, with no detectable decrease in the observed CO₂ growth rate (*medium confidence*).⁴⁸
{Cross-Chapter Box 6.1, TS.3.3}
- D.2.2 Reductions in GHG emissions also lead to air quality improvements. However, in the near term,⁴⁹ even in scenarios with strong reduction of GHGs, as in the low and very low GHG emissions scenarios (SSP1-2.6 and SSP1-1.9), these improvements

⁴⁶ A general term for how the climate system responds to a radiative forcing (Glossary).

⁴⁷ The choice of emissions metric depends on the purposes for which gases or forcing agents are being compared. This Report contains updated emissions metric values and assesses new approaches to aggregating gases.

⁴⁸ For other GHGs, there was insufficient literature available at the time of the assessment to assess detectable changes in their atmospheric growth rate during 2020.

⁴⁹ Near term: 2021–2040.

are not sufficient in many polluted regions to achieve air quality guidelines specified by the World Health Organization (*high confidence*). Scenarios with targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but from 2040, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions, with the magnitude of the benefit varying between regions (*high confidence*).
{6.6, 6.7, Box TS.7}.

- D.2.3 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) would have rapid and sustained effects to limit human-caused climate change, compared with scenarios with high or very high GHG emissions (SSP3-7.0 or SSP5-8.5), but early responses of the climate system can be masked by natural variability. For global surface temperature, differences in 20-year trends would *likely* emerge during the near term under a very low GHG emissions scenario (SSP1-1.9), relative to a high or very high GHG emissions scenario (SSP3-7.0 or SSP5-8.5). The response of many other climate variables would emerge from natural variability at different times later in the 21st century (*high confidence*).
{4.6, Cross-Section Box TS.1} (Figure SPM.8, Figure SPM.10)
- D.2.4 Scenarios with very low and low GHG emissions (SSP1-1.9 and SSP1-2.6) would lead to substantially smaller changes in a range of CIDs³⁶ beyond 2040 than under high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5). By the end of the century, scenarios with very low and low GHG emissions would strongly limit the change of several CIDs, such as the increases in the frequency of extreme sea level events, heavy precipitation and pluvial flooding, and exceedance of dangerous heat thresholds, while limiting the number of regions where such exceedances occur, relative to higher GHG emissions scenarios (*high confidence*). Changes would also be smaller in very low compared to low GHG emissions scenarios, as well as for intermediate (SSP2-4.5) compared to high or very high GHG emissions scenarios (*high confidence*).
{9.6, 11.2, 11.3, 11.4, 11.5, 11.6, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, TS.4.3}

Summary for Policymakers

Summary for Policymakers

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Table of Contents

A: Introduction	5
Box SPM.1 AR6 Common Climate Dimensions, Global Warming Levels and Reference Periods	7
B: Observed and Projected Impacts and Risks	8
Observed Impacts from Climate Change	9
Vulnerability and Exposure of Ecosystems and People	12
Risks in the near term (2021–2040)	13
Mid to Long-term Risks (2041–2100)	14
Complex, Compound and Cascading Risks	18
Impacts of Temporary Overshoot	19
C: Adaptation Measures and Enabling Conditions	20
Current Adaptation and its Benefits	20
Future Adaptation Options and their Feasibility	21
Limits to Adaptation	26
Avoiding Maladaptation	27
Enabling Conditions	27
D: Climate Resilient Development	28
Conditions for Climate Resilient Development	29
Enabling Climate Resilient Development	29
Climate Resilient Development for Natural and Human Systems	31
Achieving Climate Resilient Development	33

A: Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group II (WGII) contribution to the Sixth Assessment Report (AR6) of the IPCC¹. The report builds on the WGII contribution to the Fifth Assessment Report (AR5) of the IPCC, three Special Reports², and the Working Group I (WGI) contribution to the AR6 cycle.

This report recognizes the interdependence of climate, ecosystems and biodiversity³, and human societies (Figure SPM.1) and integrates knowledge more strongly across the natural, ecological, social and economic sciences than earlier IPCC assessments. The assessment of climate change impacts and risks as well as adaptation is set against concurrently unfolding non-climatic global trends e.g., biodiversity loss, overall unsustainable consumption of natural resources, land and ecosystem degradation, rapid urbanisation, human demographic shifts, social and economic inequalities and a pandemic.

The scientific evidence for each key finding is found in the 18 chapters of the underlying report and in the 7 cross-chapter papers as well as the integrated synthesis presented in the Technical Summary (hereafter TS) and referred to in curly brackets {}. Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language⁴. The WGII Global to Regional Atlas (Annex I) facilitates exploration of key synthesis findings across the WGII regions.

The concept of risk is central to all three AR6 Working Groups. A risk framing and the concepts of adaptation, vulnerability, exposure, resilience, equity and justice, and transformation provide alternative, overlapping, complementary, and widely used entry points to the literature assessed in this WGII report.

Across all three AR6 working groups, **risk**⁵ provides a framework for understanding the increasingly severe, interconnected and often irreversible impacts of climate change on ecosystems, biodiversity, and human systems; differing impacts across regions, sectors and communities; and how to best reduce adverse consequences for current and future generations. In the context of climate change, risk can arise from the dynamic interactions among climate-related **hazards**⁶ (see Working Group I), the **exposure**⁷ and **vulnerability**⁸ of affected human and ecological systems. The risk that can be introduced by human responses to climate change is a new aspect considered in the risk concept. This report identifies 127 key risks⁹. {1.3, 16.5}

The vulnerability of exposed human and natural systems is a component of risk, but also, independently, an important focus in the literature. Approaches to analysing and assessing vulnerability have evolved since previous IPCC assessments. Vulnerability is widely understood to differ within communities and across societies, regions and countries, also changing through time.

Adaptation¹⁰ plays a key role in reducing exposure and vulnerability to climate change. Adaptation in ecological systems includes autonomous adjustments through ecological and evolutionary processes. In human systems, adaptation can be anticipatory or reactive, as well as incremental

1 Decision IPCC/CLVI-3, The assessment covers scientific literature accepted for publication by 1 September 2021.

2 The three Special Reports are: 'Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5)'; 'Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL)'; 'IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)'.

3 Biodiversity: Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

4 Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Assessed likelihood is typeset in italics, e.g., *very likely*. This is consistent with AR5 and the other AR6 Reports.

5 Risk is defined as the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems.

6 Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. Physical climate conditions that may be associated with hazards are assessed in Working Group I as climatic impact-drivers.

7 Exposure is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected.

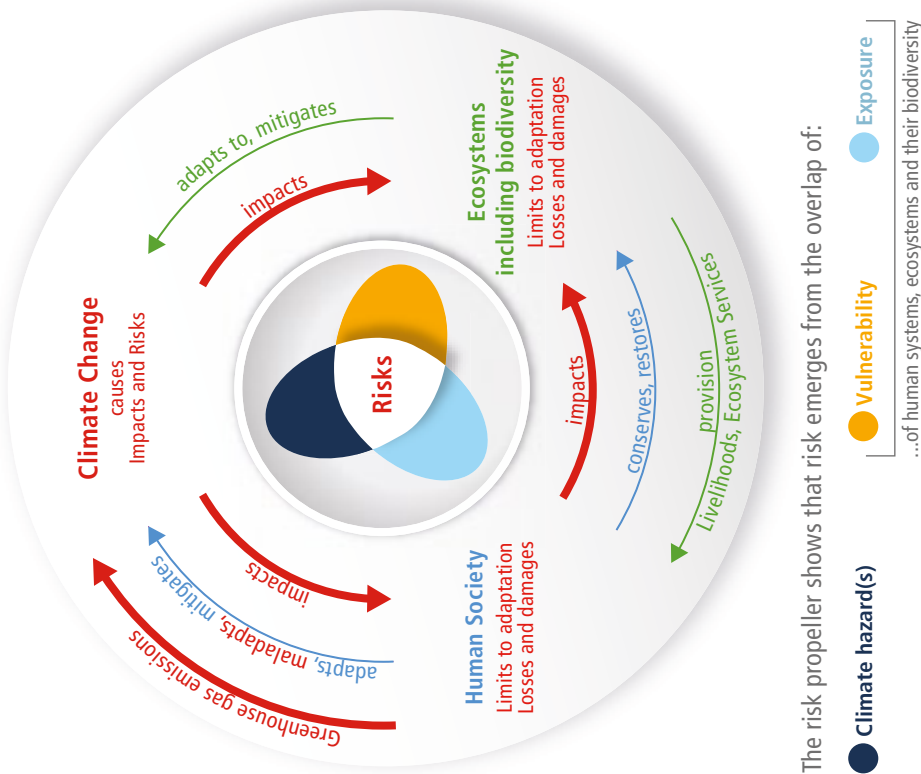
8 Vulnerability in this report is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

9 Key risks have potentially severe adverse consequences for humans and social-ecological systems resulting from the interaction of climate related hazards with vulnerabilities of societies and systems exposed.

10 Adaptation is defined, in human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this.

From climate risk to climate resilient development: climate, ecosystems (including biodiversity) and human society as coupled systems

(a) Main interactions and trends



The risk propeller shows that risk emerges from the overlap of:

- Climate hazard(s)
 - Vulnerability
 - Exposure
- ...of human systems, ecosystems and their biodiversity

(b) Options to reduce climate risks and establish resilience

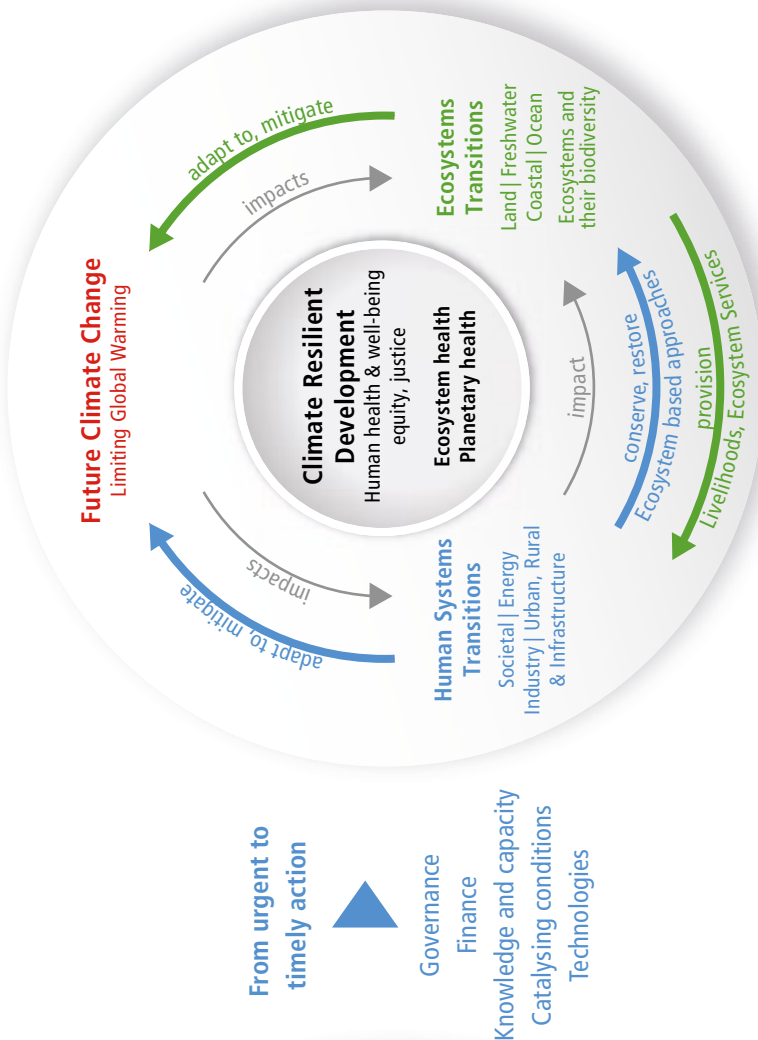


Figure SPM.1 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer opportunities for the future.

(a) Human society causes climate change. Climate change, through hazards, exposure and vulnerability generates impacts and risks that can surpass limits to adaptation and result in losses and damages. Human society can adapt to, maladapt and mitigate climate change, ecosystems can adapt and mitigate within limits. Ecosystems and their biodiversity provision livelihoods and ecosystem services. Human society impacts ecosystems and can restore and conserve them.

(b) Meeting the objectives of climate resilient development thereby supporting human, ecosystem and planetary health, as well as human well-being, requires society and ecosystems to move over (transition) to a more resilient state. The recognition of climate risks can strengthen adaptation and mitigation actions and transitions that reduce risks. Taking action is enabled by governance, finance, knowledge and capacity building, technology and catalysing conditions. Transformation entails system transitions strengthening the resilience of ecosystems and society (Section D). In a) arrow colours represent principle human society interactions (blue), ecosystem (including biodiversity) interactions (green) and the impacts of climate change and human activities, including losses and damages, under continued climate change (red). In b) arrow colours represent human system interactions (blue), ecosystem (including biodiversity) interactions (green) and reduced impacts from climate change and human activities (grey). [1.2, Figure 1.2, Figure TS.2]

and/ or transformational. The latter changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts. Adaptation is subject to hard and soft limits¹¹.

Resilience¹² in the literature has a wide range of meanings. Adaptation is often organized around resilience as bouncing back and returning to a previous state after a disturbance. More broadly the term describes not just the ability to maintain essential function, identity and structure, but also the capacity for transformation.

This report recognises the value of diverse forms of knowledge such as scientific, as well as Indigenous knowledge and local knowledge in understanding and evaluating climate adaptation processes and actions to reduce risks from human-induced climate change. AR6 highlights adaptation solutions which are effective, feasible¹³, and conform to principles of justice¹⁴. The term climate justice, while used in different ways in different contexts by different communities, generally includes three principles: *distributive justice* which refers to the allocation of burdens and benefits among individuals, nations and generations; *procedural justice* which refers to who decides and participates in decision-making; and *recognition* which entails basic respect and robust engagement with and fair consideration of diverse cultures and perspectives.

Effectiveness refers to the extent to which an action reduces vulnerability and climate-related risk, increases resilience, and avoids maladaptation¹⁵.

This report has a particular focus on transformation¹⁶ and system transitions in energy; land, ocean, coastal and freshwater ecosystems; urban, rural and infrastructure; and industry and society. These transitions make possible the adaptation required for high levels of human health and well-being, economic and social resilience, ecosystem health¹⁷, and planetary health¹⁸ (Figure SPM.1). These system transitions are also important for achieving the low global warming levels (Working Group III) that would avoid many limits to adaptation¹¹. The report also assesses economic and non-economic losses and damages¹⁹. This report labels the process of implementing mitigation and adaptation together in support of sustainable development for all as climate resilient development²⁰.

Box SPM.1 | AR6 Common Climate Dimensions, Global Warming Levels and Reference Periods

Assessments of climate risks consider possible future climate change, societal development and responses. This report assesses literature including that based on climate model simulations that are part of the fifth and sixth Coupled Model Intercomparison Project Phase (CMIP5, CMIP6) of the World Climate Research Programme. Future projections are driven by emissions and/or concentrations from illustrative Representative Concentration Pathways (RCPs)²¹ and Shared Socioeconomic Pathways (SSPs)²² scenarios, respectively²³. Climate impacts literature is based primarily on climate projections assessed in AR5 or earlier, or assumed global warming levels, though some recent impacts literature uses newer projections based on the CMIP6 exercise. Given differences in the impacts literature regarding

- 11 Adaptation limits: The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions.
Hard adaptation limit—No adaptive actions are possible to avoid intolerable risks.
Soft adaptation limit—Options may exist but are currently not available to avoid intolerable risks through adaptive action.
- 12 Resilience in this report is defined as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation. Resilience is a positive attribute when it maintains such a capacity for adaptation, learning, and/or transformation.
- 13 Feasibility refers to the potential for an adaptation option to be implemented.
- 14 Justice is concerned with setting out the moral or legal principles of fairness and equity in the way people are treated, often based on the ethics and values of society. *Social justice* comprises just or fair relations within society that seek to address the distribution of wealth, access to resources, opportunity and support according to principles of justice and fairness. *Climate justice* comprises justice that links development and human rights to achieve a rights-based approach to addressing climate change.
- 15 Maladaptation refers to actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.
- 16 Transformation refers to a change in the fundamental attributes of natural and human systems.
- 17 Ecosystem health: a metaphor used to describe the condition of an ecosystem, by analogy with human health. Note that there is no universally accepted benchmark for a healthy ecosystem. Rather, the apparent health status of an ecosystem is judged on the ecosystem's resilience to change, with details depending upon which metrics (such as species richness and abundance) are employed in judging it and which societal aspirations are driving the assessment.
- 18 Planetary health: a concept based on the understanding that human health and human civilisation depend on ecosystem health and the wise stewardship of ecosystems.
- 19 In this report, the term 'losses and damages' refers to adverse observed impacts and/or projected risks and can be economic and/or non-economic.
- 20 In the WGII report, climate resilient development refers to the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development for all.
- 21 RCP-based scenarios are referred to as RCPy, where 'y' refers to the level of radiative forcing (in watts per square meter, or W m⁻²) resulting from the scenario in the year 2100.
- 22 SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socioeconomic Pathway describing the socioeconomic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square meter, or W m⁻²) resulting from the scenario in the year 2100.
- 23 IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

Box SPM.1 (continued)

socioeconomic details and assumptions, WGII chapters contextualize impacts with respect to exposure, vulnerability and adaptation as appropriate for their literature, this includes assessments regarding sustainable development and climate resilient development. There are many emissions and socioeconomic pathways that are consistent with a given global warming outcome. These represent a broad range of possibilities as available in the literature assessed that affect future climate change exposure and vulnerability. Where available, WGII also assesses literature that is based on an integrative SSP-RCP framework where climate projections obtained under the RCP scenarios are analysed against the backdrop of various illustrative SSPs²². The WGII assessment combines multiple lines of evidence including impacts modelling driven by climate projections, observations, and process understanding. {1.2, 16.5, 18.2, CCB CLIMATE, WGI AR6 SPM.C, WGI AR6 Box SPM.1, WGI AR6 1.6, WGI AR6 12, AR5 WGI}

A common set of reference years and time periods are adopted for assessing climate change and its impacts and risks: the reference period 1850–1900 approximates pre-industrial global surface temperature, and three future reference periods cover the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100). {CCB CLIMATE}

Common levels of global warming relative to 1850–1900 are used to contextualize and facilitate analysis, synthesis and communication of assessed past, present and future climate change impacts and risks considering multiple lines of evidence. Robust geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached. {16.5, CCB CLIMATE, WGI AR6 Box SPM.1, WGI AR6 4.2, WGI AR6 CCB11.1}

WGI assessed the increase in global surface temperature is 1.09 [0.95 to 1.20]²⁴ °C in 2011–2020 above 1850–1900. The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22] °C).²⁵ Considering all five illustrative scenarios assessed by WGI, there is at least a greater than 50% likelihood that global warming will reach or exceed 1.5°C in the near-term, even for the very low greenhouse gas emissions scenario²⁶. {WGI AR6 SPM A1.2, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1, WGI AR6 CCB 2.3}

B: Observed and Projected Impacts and Risks

Since AR5, the knowledge base on observed and projected impacts and risks generated by climate hazards, exposure and vulnerability has increased with impacts attributed to climate change and key risks identified across the report. Impacts and risks are expressed in terms of their damages, harms, economic, and non-economic losses. Risks from observed vulnerabilities and responses to climate change are highlighted. Risks are projected for the near-term (2021–2040), the mid (2041–2060) and long term (2081–2100), at different global warming levels and for pathways that overshoot 1.5°C global warming level for multiple decades²⁷. Complex risks result from multiple climate hazards occurring concurrently, and from multiple risks interacting, compounding overall risk and resulting in risks transmitting through interconnected systems and across regions.

²⁴ In the WGI report, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

²⁵ Since AR5, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

²⁶ Global warming of 1.5°C relative to 1850–1900 would be exceeded during the 21st century under the intermediate, high and very high greenhouse gas emissions scenarios considered in this report (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high greenhouse gas emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high greenhouse gas emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low greenhouse gas emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low greenhouse gas emissions scenario (SSP1-1.9). Furthermore, for the very low greenhouse gas emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

²⁷ Overshoot: In this report, pathways that first exceed a specified global warming level (usually 1.5°C, by more than 0.1°C), and then return to or below that level again before the end of a specified period of time (e.g., before 2100). Sometimes the magnitude and likelihood of the overshoot is also characterized. The overshoot duration can vary from at least one decade up to several decades.

Observed Impacts from Climate Change

- B.1** Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability. Some development and adaptation efforts have reduced vulnerability. Across sectors and regions the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt. (*high confidence*) (Figure SPM.2) {TS B.1, Figure TS.5, 1.3, 2.3, 2.4, 2.6, 3.3, 3.4, 3.5, 4.2, 4.3, 5.2, 5.12, 6.2, 7.2, 8.2, 9.6, 9.8, 9.10, 9.11, 10.4, 11.3, 12.3, 12.4, 13.10, 14.4, 14.5, 15.3, 16.2, CCP1.2, CCP3.2, CCP4.1, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB DISASTER, CCB EXTREMES, CCB ILLNESS, CCB MIGRATE, CCB NATURAL, CCB SLR}
- B.1.1** Widespread, pervasive impacts to ecosystems, people, settlements, and infrastructure have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought and fire weather (*high confidence*). Increasingly since AR5, these observed impacts have been attributed²⁸ to human-induced climate change particularly through increased frequency and severity of extreme events. These include increased heat-related human mortality (*medium confidence*), warm-water coral bleaching and mortality (*high confidence*), and increased drought-related tree mortality (*high confidence*). Observed increases in areas burned by wildfires have been attributed to human-induced climate change in some regions (*medium to high confidence*). Adverse impacts from tropical cyclones, with related losses and damages¹⁹, have increased due to sea level rise and the increase in heavy precipitation (*medium confidence*). Impacts in natural and human systems from slow-onset processes²⁹ such as ocean acidification, sea level rise or regional decreases in precipitation have also been attributed to human induced climate change (*high confidence*). {1.3, 2.3, 2.4, 2.5, 3.2, 3.4, 3.5, 3.6, 4.2, 5.2, 5.4, 5.6, 5.12, 7.2, 9.6, 9.7, 9.8, 9.11, 11.3, Box 11.1, Box 11.2, Table 11.9, 12.3, 12.4, 13.3, 13.5, 13.10, 14.2, 14.5, 15.7, 15.8, 16.2, CCP1.2, CCP2.2, Box CCP5.1, CCP7.3, CCB DISASTER, CCB EXTREME, CCB ILLNESS, WGI AR6 SPM.3, WGI AR6 9, WGI AR6 11.3–11.8, SROCC Chapter 4}
- B.1.2** Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (*high confidence*). The extent and magnitude of climate change impacts are larger than estimated in previous assessments (*high confidence*). Widespread deterioration of ecosystem structure and function, resilience and natural adaptive capacity, as well as shifts in seasonal timing have occurred due to climate change (*high confidence*), with adverse socioeconomic consequences (*high confidence*). Approximately half of the species assessed globally have shifted polewards or, on land, also to higher elevations (*very high confidence*). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*), as well as mass mortality events on land and in the ocean (*very high confidence*) and loss of kelp forests (*high confidence*). Some losses are already irreversible, such as the first species extinctions driven by climate change (*medium confidence*). Other impacts are approaching irreversibility such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (*medium confidence*) and Arctic ecosystems driven by permafrost thaw (*high confidence*). (Figure SPM.2a). {TS B.1, Figure TS.5, 2.3, 2.4, 3.4, 3.5, 4.2, 4.3, 4.5, 9.6, 10.4, 11.3, 12.3, 12.8, 13.3, 13.4, 13.10, 14.4, 14.5, 14.6, 15.3, 16.2, CCP1.2, CCP3.2, CCP4.1, CCP5.2, Figure CCP5.4, CCP6.1, CCP6.2, CCP7.2, CCP7.3, CCB EXTREMES, CCB ILLNESS, CCB MOVING PLATE, CCB NATURAL, CCB PALEO, CCB SLR, SROCC 2.3}
- B.1.3** Climate change including increases in frequency and intensity of extremes have reduced food and water security, hindering efforts to meet Sustainable Development Goals (*high confidence*). Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally (*medium confidence*), related negative impacts were mainly in mid- and low latitude regions but positive impacts occurred in some high latitude regions (*high confidence*). Ocean warming and ocean acidification have adversely affected food production from shellfish aquaculture and fisheries in some oceanic regions (*high confidence*). Increasing weather and climate extreme events have exposed millions of people to acute food insecurity³⁰ and reduced water security, with the largest impacts observed in many locations and/or communities in Africa, Asia, Central and South America, Small Islands and the Arctic (*high confidence*). Jointly, sudden losses of food production and access to food compounded by decreased diet diversity have increased malnutrition in many communities (*high confidence*), especially for Indigenous Peoples, small-scale food producers and low-income households (*high confidence*), with children, elderly people and pregnant women particularly impacted (*high confidence*). Roughly half of the world's population currently experience severe water scarcity for at least some part of the year due to climatic and non-climatic drivers (*medium confidence*). (Figure SPM.2b) {3.5, 4.3, 4.4, Box 4.1, 5.2, 5.4, 5.8, 5.9, 5.12, 7.1, 7.2, 9.8, 10.4, 11.3, 12.3, 13.5, 14.4, 14.5, 15.3, 16.2, CCP5.2, CCP6.2}

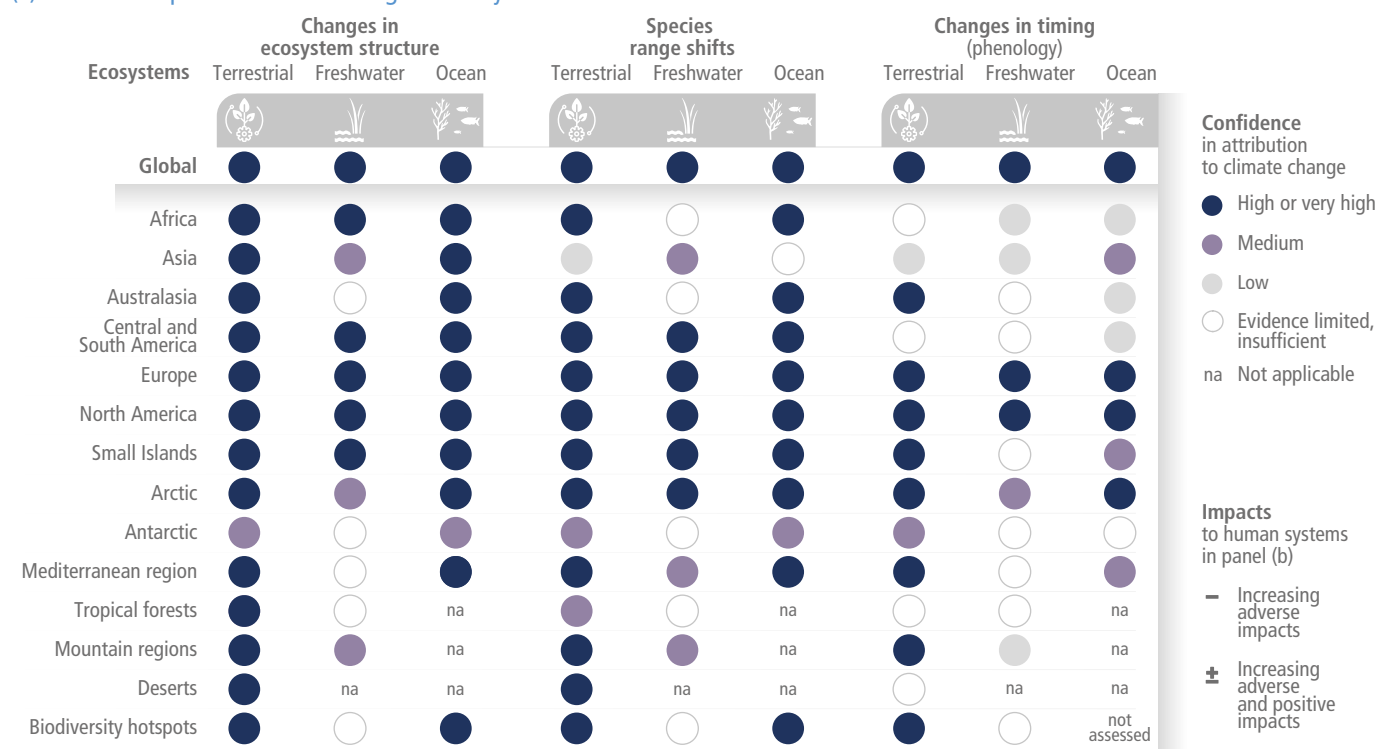
28 Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of confidence. {Annex II Glossary, CWGB ATTRIB}

29 Impacts of climate change are caused by slow onset and extreme events. Slow onset events are described among the climatic-impact drivers of the WGI AR6 and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization (<https://interactive-atlas.ipcc.ch>).

30 Acute food insecurity can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and used to assess the need for humanitarian action.

Impacts of climate change are observed in many ecosystems and human systems worldwide

(a) Observed impacts of climate change on ecosystems



(b) Observed impacts of climate change on human systems

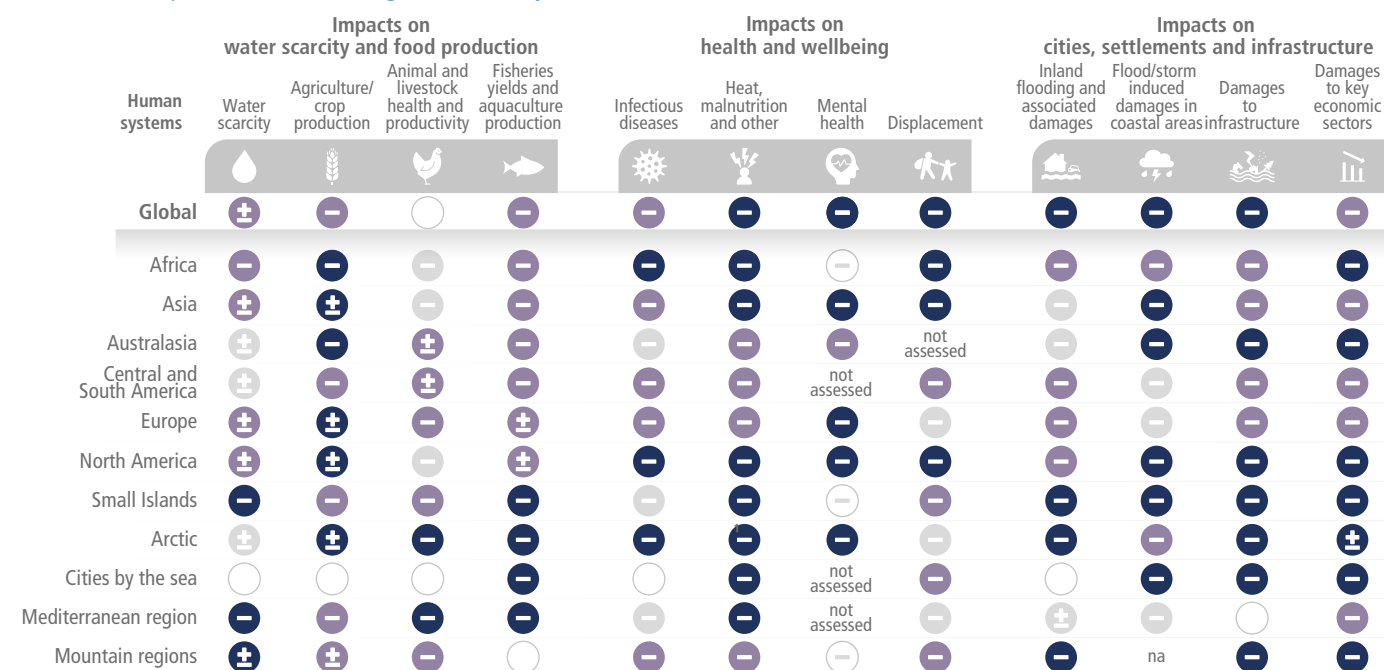


Figure SPM.2 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For that reason they can be assessed with higher confidence than regional studies, which may often rely on smaller studies that have more limited data. Regional assessments consider evidence on impacts across an entire region and do not focus on any country in particular.

(a) Climate change has already altered terrestrial, freshwater and ocean ecosystems at global scale, with multiple impacts evident at regional and local scales where there is sufficient literature to make an assessment. Impacts are evident on ecosystem structure, species geographic ranges and timing of seasonal life cycles (phenology) (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.1).

(b) Climate change has already had diverse adverse impacts on human systems, including on water security and food production, health and well-being, and cities, settlements and infrastructure. The + and – symbols indicate the direction of observed impacts, with a – denoting an increasing adverse impact and a ± denoting that, within a region or globally, both adverse and positive impacts have been observed (e.g., adverse impacts in one area or food item may occur with positive impacts in another area or food item). Globally, ‘–’ denotes an overall adverse impact; ‘Water scarcity’ considers, e.g., water availability in general, groundwater, water quality, demand for water, drought in cities. Impacts on food production were assessed by excluding non-climatic drivers of production increases; Global assessment for agricultural production is based on the impacts on global aggregated production; ‘Reduced animal and livestock health and productivity’ considers, e.g., heat stress, diseases, productivity, mortality; ‘Reduced fisheries yields and aquaculture production’ includes marine and freshwater fisheries/production; ‘Infectious diseases’ include, e.g., water-borne and vector-borne diseases; ‘Heat, malnutrition and other’ considers, e.g., human heat-related morbidity and mortality, labour productivity, harm from wildfire, nutritional deficiencies; ‘Mental health’ includes impacts from extreme weather events, cumulative events, and vicarious or anticipatory events; ‘Displacement’ assessments refer to evidence of displacement attributable to climate and weather extremes; ‘Inland flooding and associated damages’ considers, e.g., river overflows, heavy rain, glacier outbursts, urban flooding; ‘Flood/storm induced damages in coastal areas’ include damages due to, e.g., cyclones, sea level rise, storm surges. Damages by key economic sectors are observed impacts related to an attributable mean or extreme climate hazard or directly attributed. Key economic sectors include standard classifications and sectors of importance to regions (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.2).

- B.1.4** Climate change has adversely affected physical health of people globally (*very high confidence*) and mental health of people in the assessed regions (*very high confidence*). Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions (*high confidence*). In all regions extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases has increased (*very high confidence*). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (*high confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). Water and food-borne disease risks have increased regionally from climate-sensitive aquatic pathogens, including *Vibrio* spp. (*high confidence*), and from toxic substances from harmful freshwater cyanobacteria (*medium confidence*). Although diarrheal diseases have decreased globally, higher temperatures, increased rain and flooding have increased the occurrence of diarrheal diseases, including cholera (*very high confidence*) and other gastrointestinal infections (*high confidence*). In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from weather and climate extreme events (*very high confidence*), and loss of livelihoods and culture (*high confidence*). Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens have been associated with climate-sensitive cardiovascular and respiratory distress (*high confidence*). Health services have been disrupted by extreme events such as floods (*high confidence*). {4.3, 5.12, 7.2, Box 7.3, 8.2, 8.3, Box 8.6, Figure 8.10, 9.10, Figure 9.33, Figure 9.34, 10.4, 11.3, 12.3, 13.7, 14.4, 14.5, Figure 14.8, 15.3, 16.2, CCP5.2, Table CCP5.1, CCP6.2, Figure CCP6.3, Table CCB ILLNESS.1}
- B.1.5** In urban settings, observed climate change has caused impacts on human health, livelihoods and key infrastructure (*high confidence*). Multiple climate and non-climate hazards impact cities, settlements and infrastructure and sometimes coincide, magnifying damage (*high confidence*). Hot extremes including heatwaves have intensified in cities (*high confidence*), where they have also aggravated air pollution events (*medium confidence*) and limited functioning of key infrastructure (*high confidence*). Observed impacts are concentrated amongst the economically and socially marginalized urban residents, e.g., in informal settlements (*high confidence*). Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). {4.3, 6.2, 7.1, 7.2, 9.9, 10.4, 11.3, 12.3, 13.6, 14.5, 15.3, CCP2.2, CCP4.2, CCP5.2}
- B.1.6** Overall adverse economic impacts attributable to climate change, including slow-onset and extreme weather events, have been increasingly identified (*medium confidence*). Some positive economic effects have been identified in regions that have benefited from lower energy demand as well as comparative advantages in agricultural markets and tourism (*high confidence*). Economic damages from climate change have been detected in climate-exposed sectors, with regional effects to agriculture, forestry, fishery, energy, and tourism (*high confidence*), and through outdoor labour productivity (*high confidence*). Some extreme weather events, such as tropical cyclones, have reduced economic growth in the short-term (*high confidence*). Non-climatic factors including some patterns of settlement, and siting of infrastructure have contributed to the exposure of more assets to extreme climate hazards increasing the magnitude of the losses (*high confidence*). Individual livelihoods have been affected through changes in agricultural productivity, impacts on human health and food security, destruction of homes and infrastructure, and loss of property and income, with adverse effects on gender and social equity (*high confidence*). {3.5, 4.2, 5.12, 6.2, 7.2, 8.2, 9.6, 10.4, 13.10, 14.5, Box 14.6, 16.2, Table 16.5, 18.3, CCP6.2, CCB GENDER, CWGB ECONOMICS}
- B.1.7** Climate change is contributing to humanitarian crises where climate hazards interact with high vulnerability (*high confidence*). Climate and weather extremes are increasingly driving displacement in all regions (*high confidence*), with Small Island States disproportionately affected (*high confidence*). Flood and drought-related acute food insecurity and malnutrition have increased in Africa (*high confidence*) and Central and South America (*high confidence*). While non-climatic factors are the dominant drivers of existing intrastate violent conflicts, in some assessed regions extreme weather and climate events have had a small, adverse impact on their length, severity or frequency, but the statistical association is weak (*medium confidence*). Through displacement and involuntary migration from extreme weather and climate events, climate change has generated and perpetuated vulnerability (*medium confidence*). {4.2, 4.3, 5.4, 7.2, 9.8, Box 9.9, Box 10.4, 12.3, 12.5, 16.2, CCB DISASTER, CCB MIGRATE}

Vulnerability and Exposure of Ecosystems and People

- B.2** Vulnerability of ecosystems and people to climate change differs substantially among and within regions (*very high confidence*), driven by patterns of intersecting socioeconomic development, unsustainable ocean and land use, inequity, marginalization, historical and ongoing patterns of inequity such as colonialism, and governance³¹ (*high confidence*). Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*). A high proportion of species is vulnerable to climate change (*high confidence*). Human and ecosystem vulnerability are interdependent (*high confidence*). Current unsustainable development patterns are increasing exposure of ecosystems and people to climate hazards (*high confidence*). {2.3, 2.4, 3.5, 4.3, 6.2, 8.2, 8.3, 9.4, 9.7, 10.4, 12.3, 14.5, 15.3, CCP5.2, CCP6.2, CCP7.3, CCP7.4, CCB GENDER}
- B.2.1** Since AR5 there is increasing evidence that degradation and destruction of ecosystems by humans increases the vulnerability of people (*high confidence*). Unsustainable land-use and land cover change, unsustainable use of natural resources, deforestation, loss of biodiversity, pollution, and their interactions, adversely affect the capacities of ecosystems, societies, communities and individuals to adapt to climate change (*high confidence*). Loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems, to meet basic needs (*high confidence*). {2.3, 2.5, 2.6, 3.5, 3.6, 4.2, 4.3, 4.6, 5.1, 5.4, 5.5, 5.7, 5.8, 7.2, 8.1, 8.2, 8.3, 8.4, 8.5, 9.6, 10.4, 11.3, 12.2, 12.5, 13.8, 14.4, 14.5, 15.3, CCP1.2, CCP1.3, CCP2.2, CCP3, CCP4.3, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCP7.4, CCB ILLNESS, CCB MOVING PLATE, CCB SLR}
- B.2.2** Non-climatic human-induced factors exacerbate current ecosystem vulnerability to climate change (*very high confidence*). Globally, and even within protected areas, unsustainable use of natural resources, habitat fragmentation, and ecosystem damage by pollutants increase ecosystem vulnerability to climate change (*high confidence*). Globally, less than 15% of the land, 21% of the freshwater and 8% of the ocean are protected areas. In most protected areas, there is insufficient stewardship to contribute to reducing damage from, or increasing resilience to, climate change (*high confidence*). {2.4, 2.5, 2.6, 3.4, 3.6, 4.2, 4.3, 5.8, 9.6, 11.3, 12.3, 13.3, 13.4, 14.5, 15.3, CCP1.2, Figure CCP1.15, CCP2.1, CCP2.2, CCP4.2, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB NATURAL}
- B.2.3** Future vulnerability of ecosystems to climate change will be strongly influenced by the past, present and future development of human society, including from overall unsustainable consumption and production, and increasing demographic pressures, as well as persistent unsustainable use and management of land, ocean, and water (*high confidence*). Projected climate change, combined with non-climatic drivers, will cause loss and degradation of much of the world's forests (*high confidence*), coral reefs and low-lying coastal wetlands (*very high confidence*). While agricultural development contributes to food security, unsustainable agricultural expansion, driven in part by unbalanced diets³², increases ecosystem and human vulnerability and leads to competition for land and/or water resources (*high confidence*). {2.2, 2.3, 2.4, 2.6, 3.4, 3.5, 3.6, 4.3, 4.5, 5.6, 5.12, 5.13, 7.2, 12.3, 13.3, 13.4, 13.10, 14.5, CCP1.2, CCP2.2, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB HEALTH, CCB NATURAL}
- B.2.4** Regions and people with considerable development constraints have high vulnerability to climatic hazards (*high confidence*). Global hotspots of high human vulnerability are found particularly in West-, Central- and East Africa, South Asia, Central and South America, Small Island Developing States and the Arctic (*high confidence*). Vulnerability is higher in locations with poverty, governance challenges and limited access to basic services and resources, violent conflict and high levels of climate-sensitive livelihoods (e.g., smallholder farmers, pastoralists, fishing communities) (*high confidence*). Between 2010–2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability (*high confidence*). Vulnerability at different spatial levels is exacerbated by inequity and marginalization linked to gender, ethnicity, low income or combinations thereof (*high confidence*), especially for many Indigenous Peoples and local communities (*high confidence*). Present development challenges causing high vulnerability are influenced by historical and ongoing patterns of inequity such as colonialism, especially for many Indigenous Peoples and local communities (*high confidence*). {4.2, 5.12, 6.2, 6.4, 7.1, 7.2, Box 7.1, 8.2, 8.3, Box 8.4, Figure 8.6, Box 9.1, 9.4, 9.7, 9.9, 10.3, 10.4, 10.6, 12.3, 12.5, Box 13.2, 14.4, 15.3, 15.6, 16.2, CCP6.2, CCP7.4}
- B.2.5** Future human vulnerability will continue to concentrate where the capacities of local, municipal and national governments, communities and the private sector are least able to provide infrastructures and basic services (*high confidence*). Under the global trend of urbanization, human vulnerability will also concentrate in informal settlements and rapidly growing smaller settlements (*high*

31 Governance: The structures, processes and actions through which private and public actors interact to address societal goals. This includes formal and informal institutions and the associated norms, rules, laws and procedures for deciding, managing, implementing and monitoring policies and measures at any geographic or political scale, from global to local.

32 Balanced diets feature plant-based foods, such as those based on coarse grains, legumes fruits and vegetables, nuts and seeds, and animal-source foods produced in resilient, sustainable and low-greenhouse gas emissions systems, as described in SRCLL.

confidence). In rural areas vulnerability will be heightened by compounding processes including high emigration, reduced habitability and high reliance on climate-sensitive livelihoods (*high confidence*). Key infrastructure systems including sanitation, water, health, transport, communications and energy will be increasingly vulnerable if design standards do not account for changing climate conditions (*high confidence*). Vulnerability will also rapidly rise in low-lying Small Island Developing States and atolls in the context of sea level rise and in some mountain regions, already characterised by high vulnerability due to high dependence on climate-sensitive livelihoods, rising population displacement, the accelerating loss of ecosystem services and limited adaptive capacities (*high confidence*). Future exposure to climatic hazards is also increasing globally due to socioeconomic development trends including migration, growing inequality and urbanization (*high confidence*). {4.5, 5.5, 6.2, 7.2, 8.3, 9.9, 9.11, 10.3, 10.4, 12.3, 12.5, 13.6, 14.5, 15.3, 15.4, 16.5, CCP2.3, CCP4.3, CCP5.2, CCP5.3, CCP5.4, CCP6.2, CCB MIGRATE}

Risks in the near term (2021–2040)

- B.3** Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (*very high confidence*). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation (*high confidence*). Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*). (Figure SPM.3, Box SPM.1) {16.4, 16.5, 16.6, CCP1.2, CCP5.3, CCB SLR, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1}
- B.3.1** Near-term warming and increased frequency, severity and duration of extreme events will place many terrestrial, freshwater, coastal and marine ecosystems at high or very high risks of biodiversity loss (*medium to very high confidence*, depending on ecosystem). Near-term risks for biodiversity loss are moderate to high in forest ecosystems (*medium confidence*), kelp and seagrass ecosystems (*high to very high confidence*), and high to very high in Arctic sea-ice and terrestrial ecosystems (*high confidence*) and warm-water coral reefs (*very high confidence*). Continued and accelerating sea level rise will encroach on coastal settlements and infrastructure (*high confidence*) and commit low-lying coastal ecosystems to submergence and loss (*medium confidence*). If trends in urbanisation in exposed areas continue, this will exacerbate the impacts, with more challenges where energy, water and other services are constrained (*medium confidence*). The number of people at risk from climate change and associated loss of biodiversity will progressively increase (*medium confidence*). Violent conflict and, separately, migration patterns, in the near-term will be driven by socioeconomic conditions and governance more than by climate change (*medium confidence*). (Figure SPM.3) {2.5, 3.4, 4.6, 6.2, 7.3, 8.7, 9.2, 9.9, 11.6, 12.5, 13.6, 13.10, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.1, CCP2.2, CCP5.3, CCP6.2, CCP6.3, CCB MIGRATE, CCB SLR}
- B.3.2** In the near term, climate-associated risks to natural and human systems depend more strongly on changes in their vulnerability and exposure than on differences in climate hazards between emissions scenarios (*high confidence*). Regional differences exist, and risks are highest where species and people exist close to their upper thermal limits, along coastlines, in close association with ice or seasonal rivers (*high confidence*). Risks are also high where multiple non-climate drivers persist or where vulnerability is otherwise elevated (*high confidence*). Many of these risks are unavoidable in the near-term, irrespective of emissions scenario (*high confidence*). Several risks can be moderated with adaptation (*high confidence*). (Figure SPM.3, Section C) {2.5, 3.3, 3.4, 4.5, 6.2, 7.1, 7.3, 8.2, 11.6, 12.4, 13.6, 13.7, 13.10, 14.5, 16.4, 16.5, CCP2.2, CCP4.3, CCP5.3, CCB SLR, WGI AR6 Table SPM.1}
- B.3.3** Levels of risk for all Reasons for Concern (RFC) are assessed to become high to very high at lower global warming levels than in AR5 (*high confidence*). Between 1.2°C and 4.5°C global warming level very high risks emerge in all five RFCs compared to just two RFCs in AR5 (*high confidence*). Two of these transitions from high to very high risk are associated with near-term warming: risks to unique and threatened systems at a median value of 1.5 [1.2 to 2.0] °C (*high confidence*) and risks associated with extreme weather events at a median value of 2.0 [1.8 to 2.5] °C (*medium confidence*). Some key risks contributing to the RFCs are projected to lead to widespread, pervasive, and potentially irreversible impacts at global warming levels of 1.5–2°C if exposure and vulnerability are high and adaptation is low (*medium confidence*). Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*). (Figure SPM.3b) {16.5, 16.6, CCB SLR}

Mid to Long-term Risks (2041–2100)

- B.4** Beyond 2040 and depending on the level of global warming, climate change will lead to numerous risks to natural and human systems (*high confidence*). For 127 identified key risks, assessed mid- and long-term impacts are up to multiple times higher than currently observed (*high confidence*). The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, and projected adverse impacts and related losses and damages escalate with every increment of global warming (*very high confidence*). (Figure SPM.3) {2.5, 3.4, 4.4, 5.2, 6.2, 7.3, 8.4, 9.2, 10.2, 11.6, 12.4, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.2, CCP3.3, CCP4.3, CCP5.3, CCP6.3, CCP7.3}
- B.4.1** Biodiversity loss and degradation, damages to and transformation of ecosystems are already key risks for every region due to past global warming and will continue to escalate with every increment of global warming (*very high confidence*). In terrestrial ecosystems, 3 to 14% of species assessed³³ will *likely* face very high risk of extinction³⁴ at global warming levels of 1.5°C, increasing up to 3 to 18% at 2°C, 3 to 29% at 3°C, 3 to 39% at 4°C, and 3 to 48% at 5°C. In ocean and coastal ecosystems, risk of biodiversity loss ranges between moderate and very high by 1.5°C global warming level and is moderate to very high by 2°C but with more ecosystems at high and very high risk (*high confidence*), and increases to high to very high across most ocean and coastal ecosystems by 3°C (*medium* to *high confidence*, depending on ecosystem). Very high extinction risk for endemic species in biodiversity hotspots is projected to at least double from 2% between 1.5°C and 2°C global warming levels and to increase at least tenfold if warming rises from 1.5°C to 3°C (*medium confidence*). (Figure SPM.3c, d, f) {2.4, 2.5, 3.4, 3.5, 12.3, 12.5, Table 12.6, 13.4, 13.10, 16.4, 16.6, CCP1.2, Figure CCP1.6, Figure CCP1.7, CCP5.3, CCP6.3, CCB PALEO}
- B.4.2** Risks in physical water availability and water-related hazards will continue to increase by the mid- to long-term in all assessed regions, with greater risk at higher global warming levels (*high confidence*). At approximately 2°C global warming, snowmelt water availability for irrigation is projected to decline in some snowmelt dependent river basins by up to 20%, and global glacier mass loss of $18 \pm 13\%$ is projected to diminish water availability for agriculture, hydropower, and human settlements in the mid- to long-term, with these changes projected to double with 4°C global warming (*medium confidence*). In Small Islands, groundwater availability is threatened by climate change (*high confidence*). Changes to streamflow magnitude, timing and associated extremes are projected to adversely impact freshwater ecosystems in many watersheds by the mid- to long-term across all assessed scenarios (*medium confidence*). Projected increases in direct flood damages are higher by 1.4 to 2 times at 2°C and 2.5 to 3.9 times at 3°C compared to 1.5°C global warming without adaptation (*medium confidence*). At global warming of 4°C, approximately 10% of the global land area is projected to face increases in both extreme high and low river flows in the same location, with implications for planning for all water use sectors (*medium confidence*). Challenges for water management will be exacerbated in the near, mid and long term, depending on the magnitude, rate and regional details of future climate change and will be particularly challenging for regions with constrained resources for water management (*high confidence*). {2.3, 4.4, 4.5, Box 4.2, Figure 4.20, 15.3, CCP5.3, CCB DISASTER, SROCC 2.3}
- B.4.3** Climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition (*high confidence*). Increases in frequency, intensity and severity of droughts, floods and heatwaves, and continued sea level rise will increase risks to food security (*high confidence*) in vulnerable regions from moderate to high between 1.5°C and 2°C global warming level, with no or low levels of adaptation (*medium confidence*). At 2°C or higher global warming level in the mid-term, food security risks due to climate change will be more severe, leading to malnutrition and micro-nutrient deficiencies, concentrated in Sub-Saharan Africa, South Asia, Central and South America and Small Islands (*high confidence*). Global warming will progressively weaken soil health and ecosystem services such as pollination, increase pressure from pests and diseases, and reduce marine animal biomass, undermining food productivity in many regions on land and in the ocean (*medium confidence*). At 3°C or higher global warming level in the long term, areas exposed to climate-related hazards will expand substantially compared with 2°C or lower global warming level (*high confidence*), exacerbating regional disparity in food security risks (*high confidence*). (Figure SPM.3) {1.1, 3.3, 4.5, 5.2, 5.4, 5.5, 5.8, 5.9, 5.12, 7.3, 8.3, 9.11, 13.5, 15.3, 16.5, 16.6, CCB MOVING PLATE, CCB SLR}

³³ Numbers of species assessed are in the tens of thousands globally.

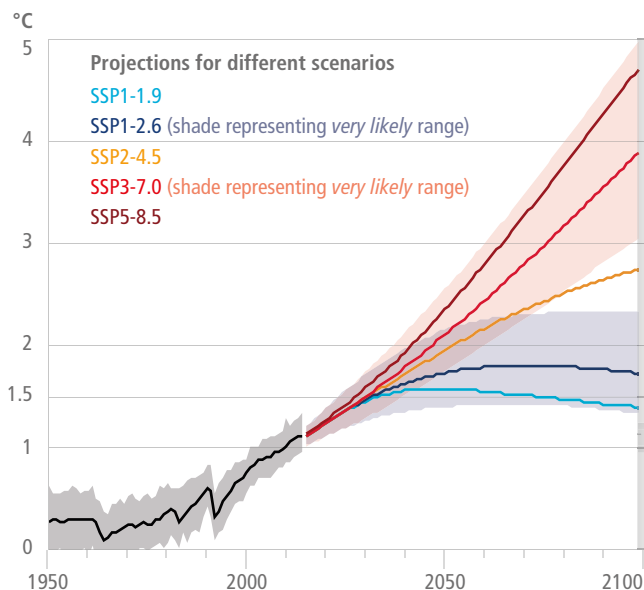
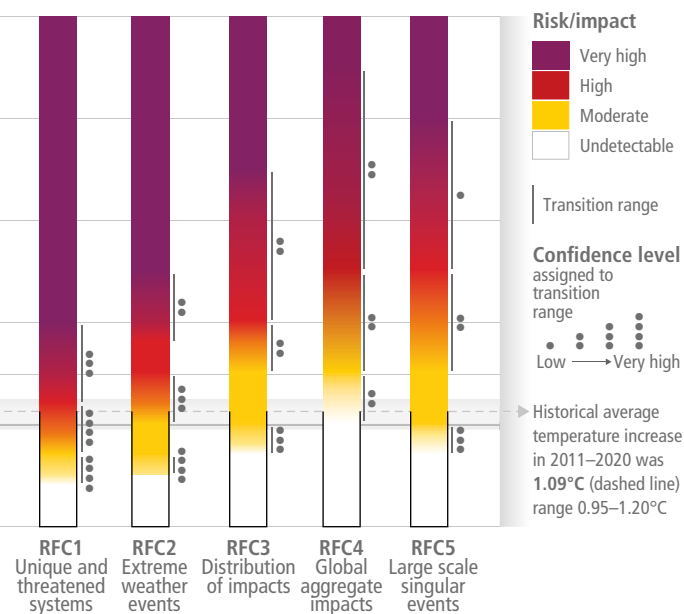
³⁴ The term 'very high risks of extinction' is used here consistently with the IUCN categories and criteria and equates with 'critically endangered'.

- B.4.4** Climate change and related extreme events will significantly increase ill health and premature deaths from the near- to long-term (*high confidence*). Globally, population exposure to heatwaves will continue to increase with additional warming, with strong geographical differences in heat-related mortality without additional adaptation (*very high confidence*). Climate-sensitive food-borne, water-borne, and vector-borne disease risks are projected to increase under all levels of warming without additional adaptation (*high confidence*). In particular, dengue risk will increase with longer seasons and a wider geographic distribution in Asia, Europe, Central and South America and sub-Saharan Africa, potentially putting additional billions of people at risk by the end of the century (*high confidence*). Mental health challenges, including anxiety and stress, are expected to increase under further global warming in all assessed regions, particularly for children, adolescents, elderly, and those with underlying health conditions (*very high confidence*). {4.5, 5.12, Box 5.10, 7.3, Figure 7.9, 8.4, 9.10, Figure 9.32, Figure 9.35, 10.4, Figure 10.11, 11.3, 12.3, Figure 12.5, Figure 12.6, 13.7, Figure 13.23, Figure 13.24, 14.5, 15.3, CCP6.2}
- B.4.5** Climate change risks to cities, settlements and key infrastructure will rise rapidly in the mid- and long-term with further global warming, especially in places already exposed to high temperatures, along coastlines, or with high vulnerabilities (*high confidence*). Globally, population change in low-lying cities and settlements will lead to approximately a billion people projected to be at risk from coastal-specific climate hazards in the mid-term under all scenarios, including in Small Islands (*high confidence*). The population potentially exposed to a 100-year coastal flood is projected to increase by about 20% if global mean sea level rises by 0.15 m relative to 2020 levels; this exposed population doubles at a 0.75 m rise in mean sea level and triples at 1.4 m without population change and additional adaptation (*medium confidence*). Sea level rise poses an existential threat for some Small Islands and some low-lying coasts (*medium confidence*). By 2100 the value of global assets within the future 1-in-100 year coastal floodplains is projected to be between US\$7.9 and US\$12.7 trillion (2011 value) under RCP4.5, rising to between US\$8.8 and US\$14.2 trillion under RCP8.5 (*medium confidence*). Costs for maintenance and reconstruction of urban infrastructure, including building, transportation, and energy will increase with global warming level (*medium confidence*), the associated functional disruptions are projected to be substantial particularly for cities, settlements and infrastructure located on permafrost in cold regions and on coasts (*high confidence*). {6.2, 9.9, 10.4, 13.6, 13.10, 15.3, 16.5, CCP2.1, CCP2.2, CCP5.3, CCP6.2, CCB SLR, SROCC 2.3, SROCC CCB9}
- B.4.6** Projected estimates of global aggregate net economic damages generally increase non-linearly with global warming levels (*high confidence*).³⁵ The wide range of global estimates, and the lack of comparability between methodologies, does not allow for identification of a robust range of estimates (*high confidence*). The existence of higher estimates than assessed in AR5 indicates that global aggregate economic impacts could be higher than previous estimates (*low confidence*).³⁶ Significant regional variation in aggregate economic damages from climate change is projected (*high confidence*) with estimated economic damages per capita for developing countries often higher as a fraction of income (*high confidence*). Economic damages, including both those represented and those not represented in economic markets, are projected to be lower at 1.5°C than at 3°C or higher global warming levels (*high confidence*). {4.4, 9.11, 11.5, 13.10, Box 14.6, 16.5, CWGB ECONOMIC}
- B.4.7** In the mid- to long-term, displacement will increase with intensification of heavy precipitation and associated flooding, tropical cyclones, drought and, increasingly, sea level rise (*high confidence*). At progressive levels of warming, involuntary migration from regions with high exposure and low adaptive capacity would occur (*medium confidence*). Compared to other socioeconomic factors the influence of climate on conflict is assessed as relatively weak (*high confidence*). Along long-term socioeconomic pathways that reduce non-climatic drivers, risk of violent conflict would decline (*medium confidence*). At higher global warming levels, impacts of weather and climate extremes, particularly drought, by increasing vulnerability will increasingly affect violent intrastate conflict (*medium confidence*). {TS B.7.4, 7.3, 16.5, CCB MIGRATE }

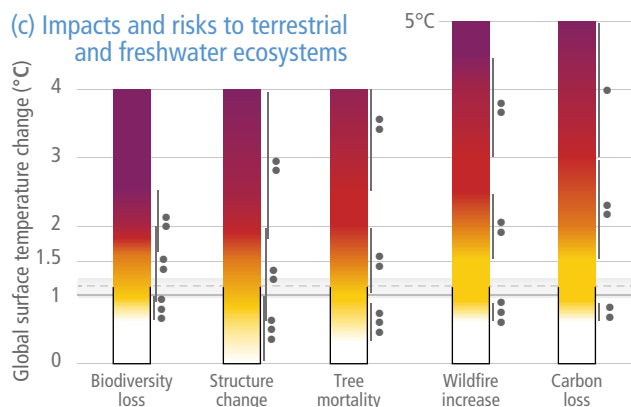
³⁵ The assessment found estimated rates of increase in projected global economic damages that were both greater than linear and less than linear as global warming level increases. There is evidence that some regions could benefit from low levels of warming (*high confidence*). [CWGB ECONOMIC]

³⁶ *Low confidence* assigned due to the assessed lack of comparability and robustness of global aggregate economic damage estimates. [CWGB ECONOMIC]

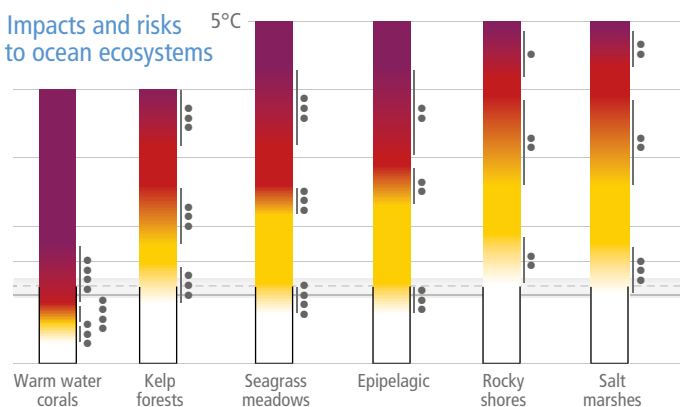
Global and regional risks for increasing levels of global warming

(a) Global surface temperature change
Increase relative to the period 1850–1900(b) Reasons for Concern (RFC)
Impact and risk assessments assuming low to no adaptation

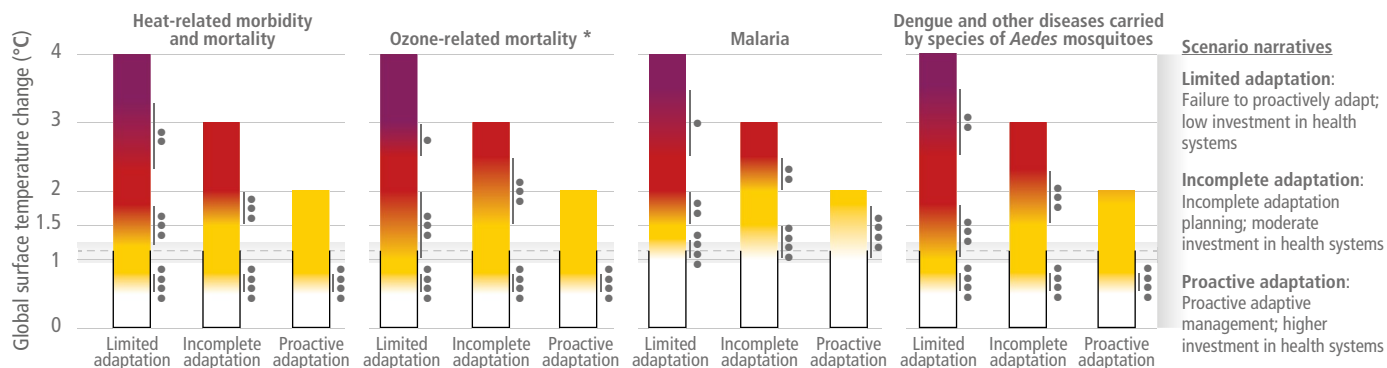
(c) Impacts and risks to terrestrial and freshwater ecosystems



(d) Impacts and risks to ocean ecosystems



(e) Climate sensitive health outcomes under three adaptation scenarios



* Mortality projections include demographic trends but do not include future efforts to improve air quality that reduce ozone concentrations.

(f) Examples of regional key risks

Absence of risk diagrams does not imply absence of risks within a region. The development of synthetic diagrams for Small Islands, Asia and Central and South America was limited due to the paucity of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socioeconomic contexts across countries within a region, and the resulting few numbers of impact and risk projections for different warming levels.

The risks listed are of at least *medium confidence level*:

Small Islands	- Loss of terrestrial, marine and coastal biodiversity and ecosystem services - Loss of lives and assets, risk to food security and economic disruption due to destruction of settlements and infrastructure - Economic decline and livelihood failure of fisheries, agriculture, tourism and from biodiversity loss from traditional agroecosystems - Reduced habitability of reef and non-reef islands leading to increased displacement - Risk to water security in almost every small island
North America	- Climate-sensitive mental health outcomes, human mortality and morbidity due to increasing average temperature, weather and climate extremes, and compound climate hazards - Risk of degradation of marine, coastal and terrestrial ecosystems, including loss of biodiversity, function, and protective services - Risk to freshwater resources with consequences for ecosystems, reduced surface water availability for irrigated agriculture, other human uses, and degraded water quality - Risk to food and nutritional security through changes in agriculture, livestock, hunting, fisheries, and aquaculture productivity and access - Risks to well-being, livelihoods and economic activities from cascading and compounding climate hazards, including risks to coastal cities, settlements and infrastructure from sea level rise
Europe	- Risks to people, economies and infrastructures due to coastal and inland flooding - Stress and mortality to people due to increasing temperatures and heat extremes - Marine and terrestrial ecosystems disruptions - Water scarcity to multiple interconnected sectors - Losses in crop production, due to compound heat and dry conditions, and extreme weather
Central and South America	- Risk to water security - Severe health effects due to increasing epidemics, in particular vector-borne diseases - Coral reef ecosystems degradation due to coral bleaching - Risk to food security due to frequent/extreme droughts - Damages to life and infrastructure due to floods, landslides, sea level rise, storm surges and coastal erosion
Aus-tralasia	- Degradation of tropical shallow coral reefs and associated biodiversity and ecosystem service values - Loss of human and natural systems in low-lying coastal areas due to sea level rise - Impact on livelihoods and incomes due to decline in agricultural production - Increase in heat-related mortality and morbidity for people and wildlife - Loss of alpine biodiversity in Australia due to less snow
Asia	- Urban infrastructure damage and impacts on human well-being and health due to flooding, especially in coastal cities and settlements - Biodiversity loss and habitat shifts as well as associated disruptions in dependent human systems across freshwater, land, and ocean ecosystems - More frequent, extensive coral bleaching and subsequent coral mortality induced by ocean warming and acidification, sea level rise, marine heat waves and resource extraction - Decline in coastal fishery resources due to sea level rise, decrease in precipitation in some parts and increase in temperature - Risk to food and water security due to increased temperature extremes, rainfall variability and drought
Africa	- Species extinction and reduction or irreversible loss of ecosystems and their services, including freshwater, land and ocean ecosystems - Risk to food security, risk of malnutrition (micronutrient deficiency), and loss of livelihood due to reduced food production from crops, livestock and fisheries - Risks to marine ecosystem health and to livelihoods in coastal communities - Increased human mortality and morbidity due to increased heat and infectious diseases (including vector-borne and diarrhoeal diseases) - Reduced economic output and growth, and increased inequality and poverty rates - Increased risk to water and energy security due to drought and heat

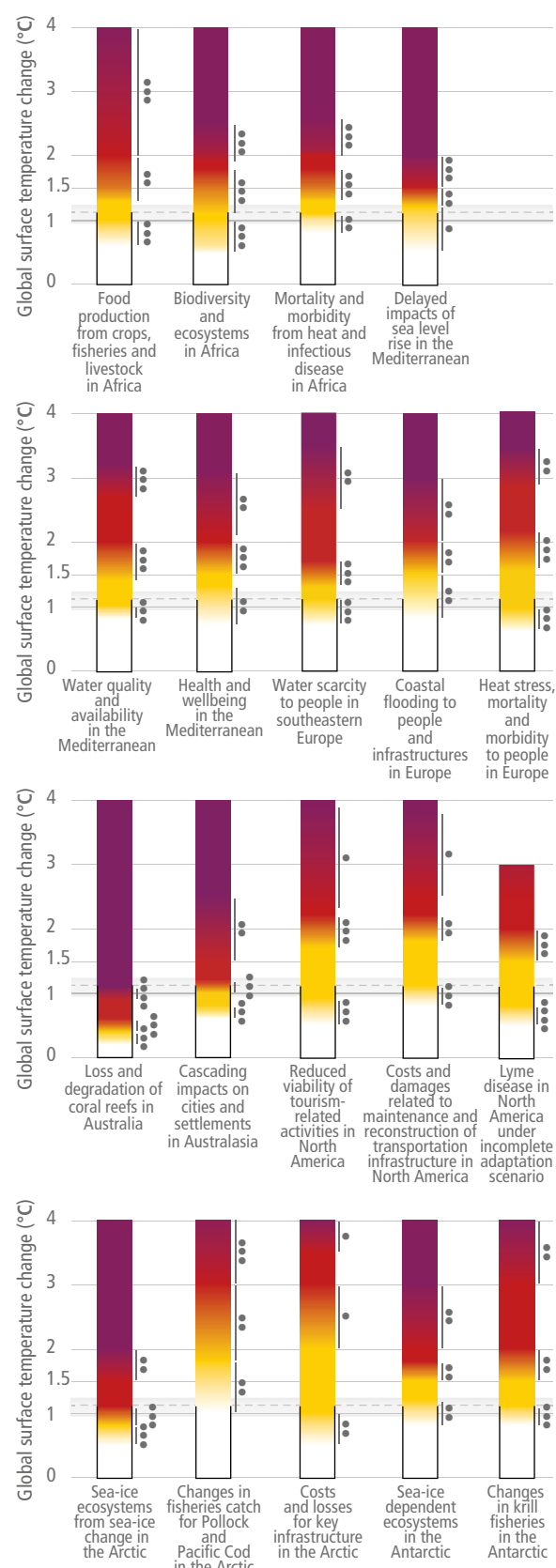


Figure SPM.3 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0 (WGI AR6 Figure SPM.8). Assessments were carried out at the global scale for (b), (c), (d) and (e).

(b) The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories. Diagrams are shown for each RFC, assuming low to no adaptation (i.e., adaptation is fragmented, localized and comprises incremental adjustments to existing practices). However, the transition to a very high risk level has an emphasis on irreversibility and adaptation limits. Undetectable risk level (white) indicates no associated impacts are detectable and attributable to climate change; moderate risk (yellow) indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk (red) indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level (purple) indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. The horizontal line denotes the present global warming of 1.09°C which is used to separate the observed, past impacts below the line from the future projected risks above it. RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its Indigenous Peoples, mountain glaciers and biodiversity hotspots. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires, and coastal flooding. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric, such as monetary damages, lives affected, species lost or ecosystem degradation at a global scale. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet disintegration or thermohaline circulation slowing. Assessment methods are described in SM16.6 and are identical to AR5, but are enhanced by a structured approach to improve robustness and facilitate comparison between AR5 and AR6.

Risks for (c) terrestrial and freshwater ecosystems and (d) ocean ecosystems. For c) and d), diagrams shown for each risk assume low to no adaptation. The transition to a very high risk level has an emphasis on irreversibility and adaptation limits.

(e) Climate-sensitive human health outcomes under three scenarios of adaptation effectiveness. The assessed projections were based on a range of scenarios, including SRES, CMIP5, and ISIMIP, and, in some cases, demographic trends. The diagrams are truncated at the nearest whole °C within the range of temperature change in 2100 under three SSP scenarios in panel (a).

(f) Examples of regional key risks. Risks identified are of at least *medium confidence* level. Key risks are identified based on the magnitude of adverse consequences (pervasiveness of the consequences, degree of change, irreversibility of consequences, potential for impact thresholds or tipping points, potential for cascading effects beyond system boundaries); likelihood of adverse consequences; temporal characteristics of the risk; and ability to respond to the risk, e.g., by adaptation. The full set of 127 assessed global and regional key risks is given in SM16.7. Diagrams are provided for some risks. The development of synthetic diagrams for Small Islands, Asia and Central and South America were limited by the availability of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socioeconomic contexts across countries within a region, and the resulting low number of impact and risk projections for different warming levels. Absence of risks diagrams does not imply absence of risks within a region. (Box SPM.1) {Figure TS.4, Figure 2.11, Figure SM3.1, Figure 7.9, Figure 9.6, Figure 11.6, Figure 13.28, 16.5, 16.6, Figure 16.15, SM16.3, SM16.4, SM16.5, SM16.6 (methodologies), SM16.7, Figure CCP4.8, Figure CCP4.10, Figure CCP6.5, WGI AR6 2, WGI AR6 SPM A.1.2, WGI AR6 Figure SPM.8}

Complex, Compound and Cascading Risks

B.5 Climate change impacts and risks are becoming increasingly complex and more difficult to manage. Multiple climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Some responses to climate change result in new impacts and risks. (*high confidence*) {1.3, 2.4, Box 2.2, Box 9.5, 11.5, 13.5, 14.6, Box 15.1, CCP1.2, CCP2.2, CCB COVID, CCB DISASTER, CCB INTEREG, CCB SRM, }

B.5.1 Concurrent and repeated climate hazards occur in all regions, increasing impacts and risks to health, ecosystems, infrastructure, livelihoods and food (*high confidence*). Multiple risks interact, generating new sources of vulnerability to climate hazards, and compounding overall risk (*high confidence*). Increasing concurrence of heat and drought events are causing crop production losses and tree mortality (*high confidence*). Above 1.5°C global warming increasing concurrent climate extremes will increase risk of simultaneous crop losses of maize in major food-producing regions, with this risk increasing further with higher global warming levels (*medium confidence*). Future sea level rise combined with storm surge and heavy rainfall will increase compound flood risks (*high confidence*). Risks to health and food production will be made more severe from the interaction of sudden food production losses from heat and drought, exacerbated by heat-induced labour productivity losses (*high confidence*). These interacting impacts will increase food prices, reduce household incomes, and lead to health risks of malnutrition and climate-related mortality with no or low levels of adaptation, especially in tropical regions (*high confidence*). Risks to food safety from climate change will further compound the risks to health by increasing food contamination of crops from mycotoxins and contamination of seafood from harmful algal blooms, mycotoxins, and chemical contaminants (*high confidence*). {Figure TS.10c, 5.2, 5.4, 5.8, 5.9, 5.11, 5.12, 7.2, 7.3, 9.8, 9.11, 10.4, 11.3, 11.5, 12.3, 13.5, 14.5, 15.3, Box 15.1, 16.6, CCP1.2, CCP6.2, , WGI AR6 SPM A.3.1, WGI AR6 SPM A.3.2, WGI AR6 SPM C.2.7}

B.5.2 Adverse impacts from climate hazards and resulting risks are cascading across sectors and regions (*high confidence*), propagating impacts along coasts and urban centres (*medium confidence*) and in mountain regions (*high confidence*). These hazards and cascading risks also trigger tipping points in sensitive ecosystems and in significantly and rapidly changing social-ecological systems impacted by ice melt, permafrost thaw and changing hydrology in polar regions (*high confidence*). Wildfires, in many regions, have affected ecosystems and species, people and their built assets, economic activity, and health (*medium to high confidence*). In cities and

settlements, climate impacts to key infrastructure are leading to losses and damages across water and food systems, and affect economic activity, with impacts extending beyond the area directly impacted by the climate hazard (*high confidence*). In Amazonia, and in some mountain regions, cascading impacts from climatic (e.g., heat) and non-climatic stressors (e.g., land use change) will result in irreversible and severe losses of ecosystem services and biodiversity at 2°C global warming level and beyond (*medium confidence*). Unavoidable sea level rise will bring cascading and compounding impacts resulting in losses of coastal ecosystems and ecosystem services, groundwater salinisation, flooding and damages to coastal infrastructure that cascade into risks to livelihoods, settlements, health, well-being, food and water security, and cultural values in the near to long-term (*high confidence*). (Figure SPM.3) {Figure TS.10, 2.5, 3.4, 3.5, Box 7.3, Box 8.7, Box 9.4, 11.5, Box 11.1, 12.3, 13.9, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.2, CCP5.2, CCP5.3, CCP6.2, CCP6.3, Box CCP6.1, Box CCP6.2, CCB EXTREMES, WGI AR6 Figure SPM.8d}

- B.5.3** Weather and climate extremes are causing economic and societal impacts across national boundaries through supply-chains, markets, and natural resource flows, with increasing transboundary risks projected across the water, energy and food sectors (*high confidence*). Supply chains that rely on specialized commodities and key infrastructure can be disrupted by weather and climate extreme events. Climate change causes the redistribution of marine fish stocks, increasing risk of transboundary management conflicts among fisheries users, and negatively affecting equitable distribution of food provisioning services as fish stocks shift from lower to higher latitude regions, thereby increasing the need for climate-informed transboundary management and cooperation (*high confidence*). Precipitation and water availability changes increases the risk of planned infrastructure projects, such as hydropower in some regions, having reduced productivity for food and energy sectors including across countries that share river basins (*medium confidence*). {Figure TS.10e-f, 3.4, 3.5, 4.5, 5.8, 5.13, 6.2, 9.4, Box 9.5, 14.5, Box 14.5, Box 14.6, CCP5.3, CCB DISASTER, CCB EXTREMES, CCB INTEREG, CCB MOVING PLATE}
- B.5.4** Risks arise from some responses that are intended to reduce the risks of climate change, including risks from maladaptation and adverse side effects of some emissions reduction and carbon dioxide removal measures (*high confidence*). Deployment of afforestation of naturally unforested land, or poorly implemented bioenergy, with or without carbon capture and storage, can compound climate-related risks to biodiversity, water and food security, and livelihoods, especially if implemented at large scales, especially in regions with insecure land tenure (*high confidence*). {Box 2.2, 4.1, 4.7, 5.13, Table 5.18, Box 9.3, Box 13.2, CCB NATURAL, CWGB BIOECONOMY}
- B.5.5** Solar radiation modification approaches, if they were to be implemented, introduce a widespread range of new risks to people and ecosystems, which are not well understood (*high confidence*). Solar radiation modification approaches have potential to offset warming and ameliorate some climate hazards, but substantial residual climate change or overcompensating change would occur at regional scales and seasonal timescales (*high confidence*). Large uncertainties and knowledge gaps are associated with the potential of solar radiation modification approaches to reduce climate change risks. Solar radiation modification would not stop atmospheric CO₂ concentrations from increasing or reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). {CWGB SRM}

Impacts of Temporary Overshoot

- B.6** If global warming transiently exceeds 1.5°C in the coming decades or later (overshoot)³⁷, then many human and natural systems will face additional severe risks, compared to remaining below 1.5°C (*high confidence*). Depending on the magnitude and duration of overshoot, some impacts will cause release of additional greenhouse gases (*medium confidence*) and some will be irreversible, even if global warming is reduced (*high confidence*). (Box SPM.1, Figure SPM.3) {2.5, 3.4, 12.3, 16.6, CCB DEEP, CCB SLR}
- B.6.1** While model-based assessments of the impacts of overshoot pathways are limited, observations and current understanding of processes permit assessment of impacts from overshoot. Additional warming, e.g., above 1.5°C during an overshoot period this century, will result in irreversible impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet, glacier melt, or by accelerating and higher committed sea level rise (*high confidence*).³⁸ Risks to human systems will increase, including those to infrastructure, low-lying coastal settlements, some ecosystem-based adaptation measures, and associated livelihoods (*high confidence*), cultural and spiritual values (*medium confidence*). Projected impacts are less severe with shorter duration and lower levels of overshoot (*medium confidence*). {2.5, 3.4, 12.3, 13.2, 16.5, 16.6, CCP1.2, CCP2.2, CCP5.3, CCP6.1, CCP6.2, CCB SLR, WGI AR6 SPM B.5, WGI AR6 SPM C.3, SROCC 2.3, SROCC 5.4}

³⁷ In this report, overshoot pathways exceed 1.5°C global warming and then return to that level, or below, after several decades.

³⁸ Despite limited evidence specifically on the impacts of a temporary overshoot of 1.5°C, a much broader evidence base from process understanding and the impacts of higher global warming levels allows a high confidence statement on the irreversibility of some impacts that would be incurred following such an overshoot.

- B.6.2** Risk of severe impacts increase with every additional increment of global warming during overshoot (*high confidence*). In high-carbon ecosystems (currently storing 3,000 to 4,000 GtC)³⁹ such impacts are already observed and are projected to increase with every additional increment of global warming, such as increased wildfires, mass mortality of trees, drying of peatlands, and thawing of permafrost, weakening natural land carbon sinks and increasing releases of greenhouse gases (*medium confidence*). The resulting contribution to a potential amplification of global warming indicates that a return to a given global warming level or below would be more challenging (*medium confidence*). {2.4, 2.5, CCP4.2, WGI AR6 SPM B.4.3, SROCC 5.4}

C: Adaptation Measures and Enabling Conditions

Adaptation, in response to current climate change, is reducing climate risks and vulnerability mostly via adjustment of existing systems. Many adaptation options exist and are used to help manage projected climate change impacts, but their implementation depends upon the capacity and effectiveness of governance and decision-making processes. These and other enabling conditions can also support climate resilient development (Section D).

Current Adaptation and its Benefits

- C.1** Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits (*very high confidence*). However, adaptation progress is unevenly distributed with observed adaptation gaps⁴⁰ (*high confidence*). Many initiatives prioritize immediate and near-term climate risk reduction which reduces the opportunity for transformational adaptation (*high confidence*). {2.6, 5.14, 7.4, 10.4, 12.5, 13.11, 14.7, 16.3, 17.3, CCP5.2, CCP5.4}
- C.1.1** Adaptation planning and implementation have continued to increase across all regions (*very high confidence*). Growing public and political awareness of climate impacts and risks has resulted in at least 170 countries and many cities including adaptation in their climate policies and planning processes (*high confidence*). Decision support tools and climate services are increasingly being used (*very high confidence*). Pilot projects and local experiments are being implemented in different sectors (*high confidence*). Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation as well as reduction of risks and damages (*very high confidence*). {1.4, 2.6, 3.5, 3.6, 4.7, 4.8, 5.4, 5.6, 5.10, 6.4, 7.4, 8.5, 9.3, 9.6, 10.4, 12.5, 13.11, 15.5, 16.3, 17.2, 17.3, 17.5, CCP5.4, CCB ADAPT, CCB NATURAL}
- C.1.2** Despite progress, adaptation gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks (*high confidence*). Most observed adaptation is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks, and focused more on planning rather than implementation (*high confidence*). Observed adaptation is unequally distributed across regions (*high confidence*), and gaps are partially driven by widening disparities between the estimated costs of adaptation and documented finance allocated to adaptation (*high confidence*). The largest adaptation gaps exist among lower income population groups (*high confidence*). At current rates of adaptation planning and implementation the adaptation gap will continue to grow (*high confidence*). As adaptation options often have long implementation times, long-term planning and accelerated implementation, particularly in the next decade, is important to close adaptation gaps, recognising that constraints remain for some regions (*high confidence*). {1.1, 1.4, 5.6, 6.3, Figure 6.4, 7.4, 8.3, 10.4, 11.3, 11.7, 13.11, Box 13.1, 15.2, 15.5, 16.3, 16.5, Box 16.1, Figure 16.4, Figure 16.5, 17.4, 18.2, CCP2.4, CCP5.4, CCB FINANCE, CCB SLR}

³⁹ At the global scale, terrestrial ecosystems currently remove more carbon from the atmosphere ($-3.4 \pm 0.9 \text{ Gt yr}^{-1}$) than they emit ($+1.6 \pm 0.7 \text{ Gt yr}^{-1}$), a net sink of $-1.9 \pm 1.1 \text{ Gt yr}^{-1}$. However, recent climate change has shifted some systems in some regions from being net carbon sinks to net carbon sources.

⁴⁰ Adaptation gaps are defined as the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerated climate change impacts and reflecting resource limitations and competing priorities.

Future Adaptation Options and their Feasibility

- C.2** There are feasible⁴¹ and effective⁴² adaptation options which can reduce risks to people and nature. The feasibility of implementing adaptation options in the near-term differs across sectors and regions (*very high confidence*). The effectiveness of adaptation to reduce climate risk is documented for specific contexts, sectors and regions (*high confidence*) and will decrease with increasing warming (*high confidence*). Integrated, multi-sectoral solutions that address social inequities, differentiate responses based on climate risk and cut across systems, increase the feasibility and effectiveness of adaptation in multiple sectors (*high confidence*). (Figure SPM.4) {Figure TS.6e, 1.4, 3.6, 4.7, 5.12, 6.3, 7.4, 11.3, 11.7, 13.2, 15.5, 17.6, CCP2.3, CCB FEASIB}

Land, Ocean and Ecosystems Transition

- C.2.1** Adaptation to water-related risks and impacts make up the majority of all documented adaptation (*high confidence*). For inland flooding, combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives (*medium confidence*). Enhancing natural water retention such as by restoring wetlands and rivers, land use planning such as no build zones or upstream forest management, can further reduce flood risk (*medium confidence*). On-farm water management, water storage, soil moisture conservation and irrigation are some of the most common adaptation responses and provide economic, institutional or ecological benefits and reduce vulnerability (*high confidence*). Irrigation is effective in reducing drought risk and climate impacts in many regions and has several livelihood benefits, but needs appropriate management to avoid potential adverse outcomes, which can include accelerated depletion of groundwater and other water sources and increased soil salinization (*medium confidence*). Large scale irrigation can also alter local to regional temperature and precipitation patterns (*high confidence*), including both alleviating and exacerbating temperature extremes (*medium confidence*). The effectiveness of most water-related adaptation options to reduce projected risks declines with increasing warming (*high confidence*). {4.1, 4.6, 4.7, Box 4.3, Box 4.6, Box 4.7, Figure 4.22, Figure 4.28, Figure 4.29, Table 4.9, 9.3, 9.7, 11.3, 12.5, 13.1, 13.2, 16.3, CCP5.4}
- C.2.2** Effective adaptation options, together with supportive public policies enhance food availability and stability and reduce climate risk for food systems while increasing their sustainability (*medium confidence*). Effective options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture (*high confidence*). Institutional feasibility, adaptation limits of crops and cost effectiveness also influence the effectiveness of the adaptation options (*limited evidence, medium agreement*). Agroecological principles and practices, ecosystem-based management in fisheries and aquaculture, and other approaches that work with natural processes support food security, nutrition, health and well-being, livelihoods and biodiversity, sustainability and ecosystem services (*high confidence*). These services include pest control, pollination, buffering of temperature extremes, and carbon sequestration and storage (*high confidence*). Trade-offs and barriers associated with such approaches include costs of establishment, access to inputs and viable markets, new knowledge and management (*high confidence*) and their potential effectiveness varies by socioeconomic context, ecosystem zone, species combinations and institutional support (*medium confidence*). Integrated, multi-sectoral solutions that address social inequities and differentiate responses based on climate risk and local situation will enhance food security and nutrition (*high confidence*). Adaptation strategies which reduce food loss and waste or support balanced diets³³ (as described in the IPCC Special Report on Climate Change and Land) contribute to nutrition, health, biodiversity and other environmental benefits (*high confidence*). {3.2, 4.7, 4.6, Box 4.3, 5.4, 5.5, 5.6, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, Box 5.10, Box 5.13, 6.3, 7.4, 10.4, 12.5, 13.5, 13.10, 14.5, CCP5.4, CCB FEASIB, CCB HEALTH, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}
- C.2.3** Adaptation for natural forests⁴³ includes conservation, protection and restoration measures. In managed forests⁴³, adaptation options include sustainable forest management, diversifying and adjusting tree species compositions to build resilience, and managing increased risks from pests and diseases and wildfires. Restoring natural forests and drained peatlands and improving sustainability of managed forests, generally enhances the resilience of carbon stocks and sinks. Cooperation, and inclusive decision making, with local communities and Indigenous Peoples, as well as recognition of inherent rights of Indigenous Peoples, is integral to successful forest adaptation in many areas. (*high confidence*) {2.6, Box 2.2, 5.6, 5.13, Table 5.23, 11.4, 12.5, 13.5, Box 14.1, Box 14.2, CCP7.5, Box CCP7.1, CCB FEASIB, CCB INDIG, CCB NATURAL}

⁴¹ In this report, feasibility refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined and increase when enabling conditions are strengthened.

⁴² Effectiveness refers to the extent to which an adaptation option is anticipated or observed to reduce climate-related risk.

⁴³ In this report, the term natural forests describes those which are subject to little or no direct human intervention, whereas the term managed forests describes those where planting or other management activities take place, including those managed for commodity production.

(a) Diverse feasible climate responses and adaptation options exist to respond to Representative Key Risks of climate change, with varying synergies with mitigation
Multidimensional feasibility and synergies with mitigation of climate responses and adaptation options relevant in the near-term, at global scale and up to 1.5°C of global warming

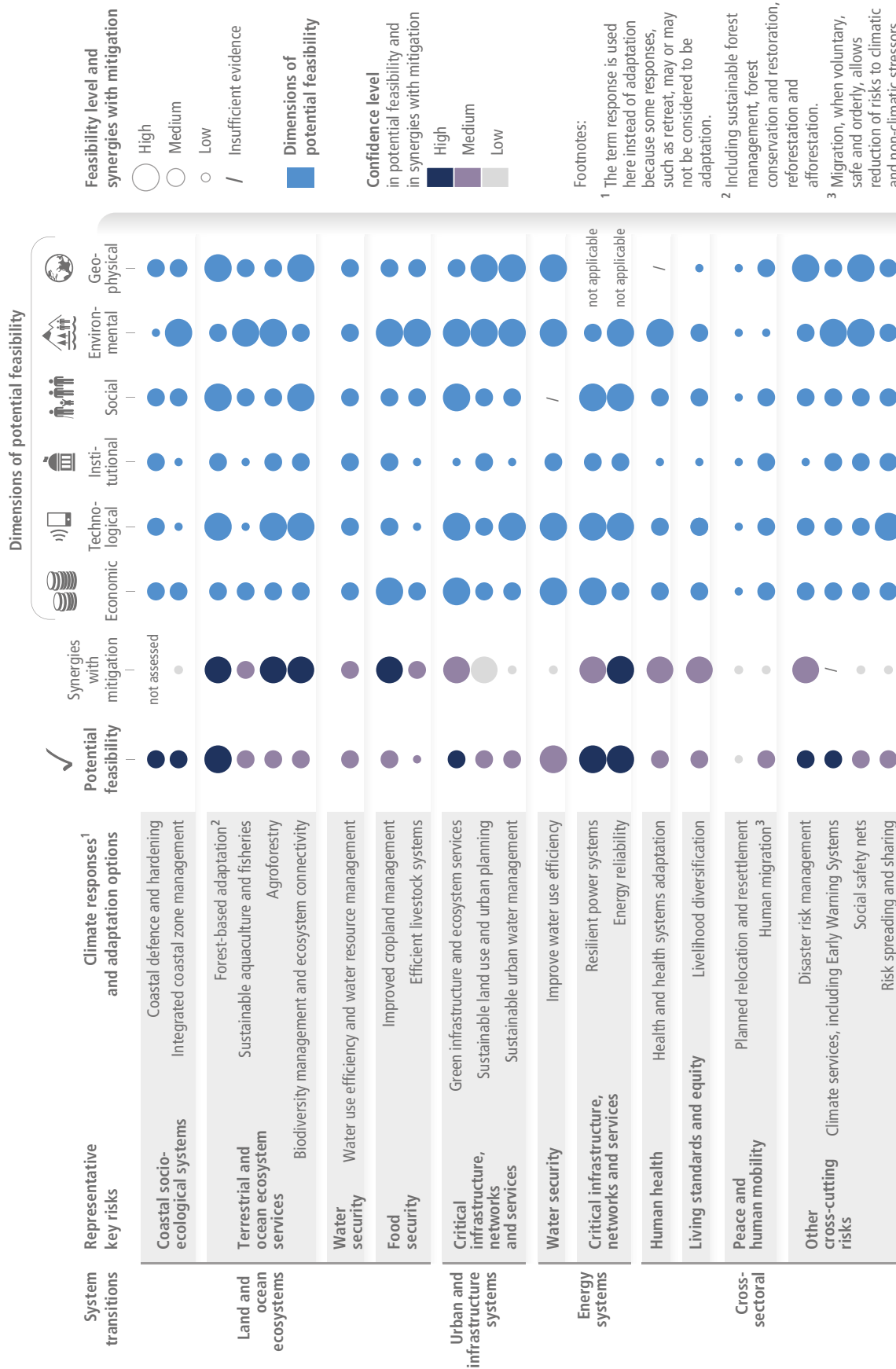
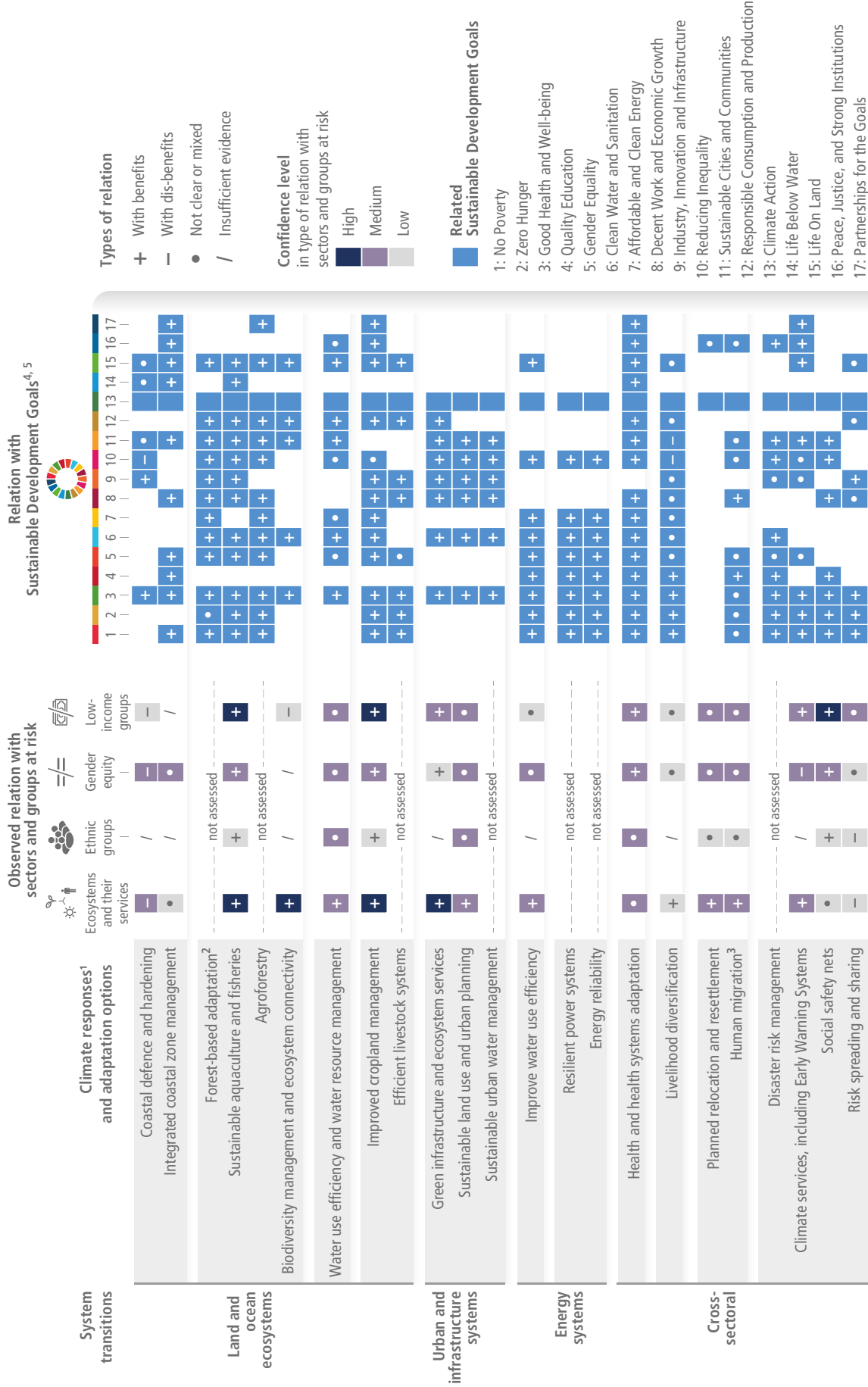


Figure SPM.4 | (a) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks (RKR), are assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher levels of warming may change, which is currently not possible to assess robustly. Climate responses and adaptation options at global scale are drawn from a set of options assessed in AR6 that have robust evidence across the feasibility dimensions. This figure shows the six feasibility dimensions (economic, technological, institutional, social, environmental and geophysical) that are used to calculate the potential feasibility of climate responses and adaptation options, along with their synergies with mitigation. For potential feasibility and feasibility dimensions, the figure shows high, medium, or low feasibility. Synergies with mitigation are identified as high, medium, and low. Insufficient evidence is denoted by a dash. [CCB FEASIB, Table SMCB FEASIB.1.1, SR1.5 4.SM.4.3]

(b) Climate responses and adaptation options have benefits for ecosystems, ethnic groups, low-income groups and the Sustainable Development Goals

Relations of sectors and groups at risk (as observed) and the SDGs (relevant in the near-term, at global scale and up to 1.5°C of global warming) with climate responses and adaptation options



Footnotes: ¹ The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. ² Including sustainable forest management, forest conservation and restoration, reforestation and afforestation. ³ Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors. ⁴ The Sustainable Development Goals (SDGs) are integrated and indivisible, and efforts to achieve any goal in isolation may trigger synergies or trade-offs with other SDGs. ⁵ Relevant in the near-term, at global scale and up to 1.5°C of global warming.

Figure SPM.4 | (b) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks, are assessed at global scale for their likely ability to reduce risks for ecosystems and social groups at risk, as well as their relation with the 17 Sustainable Development Goals (SDGs). Climate responses and adaptation options are assessed for observed benefits (+) to ecosystems and their services, ethnic groups, gender equity, and low-income groups, or observed dis-benefits (-) for these systems and groups. Where there is highly diverging evidence of benefits/ dis-benefits across the scientific literature, e.g., based on differences between regions, it is shown as not clear or mixed (•). Insufficient evidence is shown by a dash. The relation with the SDGs is assessed as having benefits (+), dis-benefits (-) or not clear or mixed (•) based on the impacts of the climate response and adaptation option on each SDG. Areas not coloured indicate there is no evidence of a relation or no interaction with the respective SDG. The climate responses and adaptation options are drawn from two assessments. For comparability of climate responses and adaptation options see Table SM17.5. {17.2, 17.5, CCB FEASIB}

SPM

- C.2.4** Conservation, protection and restoration of terrestrial, freshwater, coastal and ocean ecosystems, together with targeted management to adapt to unavoidable impacts of climate change, reduces the vulnerability of biodiversity to climate change (*high confidence*). The resilience of species, biological communities and ecosystem processes increases with size of natural area, by restoration of degraded areas and by reducing non-climatic stressors (*high confidence*). To be effective, conservation and restoration actions will increasingly need to be responsive, as appropriate, to ongoing changes at various scales, and plan for future changes in ecosystem structure, community composition and species' distributions, especially as 1.5°C global warming is approached and even more so if it is exceeded (*high confidence*). Adaptation options, where circumstances allow, include facilitating the movement of species to new ecologically appropriate locations, particularly through increasing connectivity between conserved or protected areas, targeted intensive management for vulnerable species and protecting refugial areas where species can survive locally (*medium confidence*). {2.3, 2.6, Figure 2.1, Table 2.6, 3.3, 3.6, Box 3.4, 4.6, Box 4.6, Box 11.2, 12.3, 12.5, 13.4, 14.7, CCP5.4, CCB FEASIB}
- C.2.5** Effective Ecosystem-based Adaptation⁴⁴ reduces a range of climate change risks to people, biodiversity and ecosystem services with multiple co-benefits (*high confidence*). Ecosystem-based Adaptation is vulnerable to climate change impacts, with effectiveness declining with increasing global warming (*high confidence*). Urban greening using trees and other vegetation can provide local cooling (*very high confidence*). Natural river systems, wetlands and upstream forest ecosystems reduce flood risk by storing water and slowing water flow, in most circumstances (*high confidence*). Coastal wetlands protect against coastal erosion and flooding associated with storms and sea level rise where sufficient space and adequate habitats are available until rates of sea level rise exceeds natural adaptive capacity to build sediment (*very high confidence*). {2.4, 2.5, 2.6, Table 2.7, 3.4, 3.5, 3.6, Figure 3.26, 4.6, Box 4.6, Box 4.7, 5.5, 5.14, Box 5.11, 6.3, 6.4, Figure 6.6, 7.4, 8.5, 8.6, 9.6, 9.8, 9.9, 10.2, 11.3, 12.5, 13.3, 13.4, 13.5, 14.5, Box 14.7, 16.3, 18.3, CCP5.4, CCB FEASIB.3, CCB HEALTH, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}

Urban, Rural and Infrastructure Transition

- C.2.6** Considering climate change impacts and risks in the design and planning of urban and rural settlements and infrastructure is critical for resilience and enhancing human well-being (*high confidence*). The urgent provision of basic services, infrastructure, livelihood diversification and employment, strengthening of local and regional food systems and community-based adaptation enhance lives and livelihoods, particularly of low-income and marginalised groups (*high confidence*). Inclusive, integrated and long-term planning at local, municipal, sub-national and national scales, together with effective regulation and monitoring systems and financial and technological resources and capabilities foster urban and rural system transition (*high confidence*). Effective partnerships between governments, civil society, and private sector organizations, across scales provide infrastructure and services in ways that enhance the adaptive capacity of vulnerable people (*medium to high confidence*). {5.12, 5.13, 5.14, 6.3, 6.4, Box 6.3, Box 6.6, Table 6.6, 7.4, 12.5, 13.6, 14.5, Box 14.4, Box 17.4, CCP2.3, CCP2.4, CCP5.4, CCB FEASIB}
- C.2.7** An increasing number of adaptation responses exist for urban systems, but their feasibility and effectiveness is constrained by institutional, financial, and technological access and capacity, and depends on coordinated and contextually appropriate responses across physical, natural and social infrastructure (*high confidence*). Globally, more financing is directed at physical infrastructure than natural and social infrastructure (*medium confidence*) and there is *limited evidence* of investment in the informal settlements hosting the most vulnerable urban residents (*medium to high confidence*). Ecosystem-based adaptation (e.g., urban agriculture and forestry, river restoration) has increasingly been applied in urban areas (*high confidence*). Combined ecosystem-based and structural adaptation responses are being developed, and there is growing evidence of their potential to reduce adaptation costs and contribute to flood control, sanitation, water resources management, landslide prevention and coastal protection (*medium confidence*). {3.6, Box 4.6, 5.12, 6.3, 6.4, Table 6.8, 7.4, 9.7, 9.9, 10.4, Table 10.3, 11.3, 11.7, Box 11.6, 12.5, 13.2, 13.3, 13.6, 14.5, 15.5, 17.2, Box 17.4, CCP2.3, CCP3.2, CCP5.4, CCB FEASIB, CCB SLR, SROCC SPM}

⁴⁴ Ecosystem based Adaptation (EbA) is recognised internationally under the Convention on Biological Diversity (CBD14/5). A related concept is Nature-based Solutions (NbS), which includes a broader range of approaches with safeguards, including those that contribute to adaptation and mitigation. The term 'Nature-based Solutions' is widely but not universally used in the scientific literature. The term is the subject of ongoing debate, with concerns that it may lead to the misunderstanding that NbS on its own can provide a global solution to climate change.

- C.2.8** Sea level rise poses a distinctive and severe adaptation challenge as it implies dealing with slow onset changes and increased frequency and magnitude of extreme sea level events which will escalate in the coming decades (*high confidence*). Such adaptation challenges would occur much earlier under high rates of sea level rise, in particular if low-likelihood, high impact outcomes associated with collapsing ice sheets occur (*high confidence*). Responses to ongoing sea level rise and land subsidence in low-lying coastal cities and settlements and small islands include protection, accommodation, advance and planned relocation (*high confidence*)⁴⁵. These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and development priorities, and underpinned by inclusive community engagement processes (*high confidence*). { 6.2, 10.4, 11.7, Box 11.6, 13.2, 14.5, 15.5, CCP2.3, CCB SLR, WGI AR6 SPM B.5, WGI AR6 SPM C.3, SROCC SPM C3.2 }
- C.2.9** Approximately 3.4 billion people globally live in rural areas around the world, and many are highly vulnerable to climate change. Integrating climate adaptation into social protection programs, including cash transfers and public works programmes, is highly feasible and increases resilience to climate change, especially when supported by basic services and infrastructure. Social safety nets are increasingly being reconfigured to build adaptive capacities of the most vulnerable in rural and also urban communities. Social safety nets that support climate change adaptation have strong co-benefits with development goals such as education, poverty alleviation, gender inclusion and food security. (*high confidence*) { 5.14, 9.4, 9.10, 9.11, 12.5, 14.5, CCP5.4, CCB FEASIB, CCB GENDER }

Energy System Transition

- C.2.10** Within energy system transitions, the most feasible adaptation options support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (*very high confidence*). Energy generation diversification, including with renewable energy resources and generation that can be decentralised depending on context (e.g., wind, solar, small scale hydroelectric) and demand side management (e.g., storage, and energy efficiency improvements) can reduce vulnerabilities to climate change, especially in rural populations (*high confidence*). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C to 2°C, with decreasing effectiveness at higher levels of warming (*medium confidence*). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium- to long-term, with mitigation co-benefits (*very high confidence*). { 4.6, 4.7, Figure 4.28, Figure 4.29, 10.4, Table 11.8, 13.6, Figure 13.16, Figure 13.19, 18.3, CCP5.2, CCP5.4, CCB FEASIB, CWGB BIOECONOMY }

Cross-cutting Options

- C.2.11** Strengthening the climate resiliency of health systems will protect and promote human health and well-being (*high confidence*). There are multiple opportunities for targeted investments and finance to protect against exposure to climate hazards, particularly for those at highest risk. Heat Health Action Plans that include early warning and response systems are effective adaptation options for extreme heat (*high confidence*). Effective adaptation options for water-borne and food-borne diseases include improving access to potable water, reducing exposure of water and sanitation systems to flooding and extreme weather events, and improved early warning systems (*very high confidence*). For vector-borne diseases, effective adaptation options include surveillance, early warning systems, and vaccine development (*very high confidence*). Effective adaptation options for reducing mental health risks under climate change include improving surveillance, access to mental health care, and monitoring of psychosocial impacts from extreme weather events (*high confidence*). Health and well-being would benefit from integrated adaptation approaches that mainstream health into food, livelihoods, social protection, infrastructure, water and sanitation policies requiring collaboration and coordination at all scales of governance (*very high confidence*). { 5.12, 6.3, 7.4, 9.10, Box 9.7, 11.3, 12.5, 13.7, 14.5, CCB COVID, CCB FEASIB, CCB ILLNESS }
- C.2.12** Increasing adaptive capacities minimises the negative impacts of climate-related displacement and involuntary migration for migrants and sending and receiving areas (*high confidence*). This improves the degree of choice under which migration decisions are made, ensuring safe and orderly movements of people within and between countries (*high confidence*). Some development reduces underlying vulnerabilities associated with conflict, and adaptation contributes by reducing the impacts of climate change on climate sensitive drivers of conflict (*high confidence*). Risks to peace are reduced, for example, by supporting people in climate-sensitive economic activities (*medium confidence*) and advancing women's empowerment (*high confidence*). { 7.4, Box 9.8, Box 10.2, 12.5, CCB FEASIB, CCB MIGRATE }

⁴⁵ The term 'response' is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation.

- C.2.13** There are a range of adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined (*high confidence*). For example, climate services that are inclusive of different users and providers can improve agricultural practices, inform better water use and efficiency, and enable resilient infrastructure planning (*high confidence*). {2.6, 3.6, 4.7, 5.4, 5.5, 5.6, 5.8, 5.9, 5.12, 5.14, 9.4, 9.8, 10.4, 12.5, 13.11, CCP5.4, CCB FEASIB, CCB MOVING PLATE}

Limits to Adaptation

- C.3** **Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, primarily financial, governance, institutional and policy constraints (*high confidence*). Hard limits to adaptation have been reached in some ecosystems (*high confidence*). With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits (*high confidence*).** {Figure TS.7, 1.4, 2.4, 2.5, 2.6, 3.4, 3.6, 4.7, Figure 4.30, 5.5, Table 8.6, Box 10.7, 11.7, Table 11.16, 12.5, 13.2, 13.5, 13.6, 13.10, 13.11, Figure 13.21, 14.5, 15.6, 16.4, Figure 16.8, Table 16.3, Table 16.4, CCP1.2, CCP1.3, CCP2.3, CCP3.3, CCP5.2, CCP5.4, CCP6.3, CCP7.3, CCB SLR}
- C.3.1** Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, which primarily consist of financial, governance, institutional and policy constraints (*high confidence*). For example, individuals and households in low-lying coastal areas in Australasia and Small Islands and smallholder farmers in Central and South America, Africa, Europe and Asia have reached soft limits (*medium confidence*). Inequity and poverty also constrain adaptation, leading to soft limits and resulting in disproportionate exposure and impacts for most vulnerable groups (*high confidence*). Lack of climate literacy⁴⁶ at all levels and limited availability of information and data pose further constraints to adaptation planning and implementation (*medium confidence*). {1.4, 4.7, 5.4, 8.4, Table 8.6, 9.1, 9.4, 9.5, 9.8, 11.7, 12.5, 13.5, 15.3, 15.5, 15.6, 16.4, Box 16.1, Figure 16.8, CCP5.2, CCP5.4, CCP6.3}
- C.3.2** Financial constraints are important determinants of soft limits to adaptation across sectors and all regions (*high confidence*). Although global tracked climate finance has shown an upward trend since AR5, current global financial flows for adaptation, including from public and private finance sources, are insufficient for and constrain implementation of adaptation options especially in developing countries (*high confidence*). The overwhelming majority of global tracked climate finance was targeted to mitigation while a small proportion was targeted to adaptation (*very high confidence*). Adaptation finance has come predominantly from public sources (*very high confidence*). Adverse climate impacts can reduce the availability of financial resources by incurring losses and damages and through impeding national economic growth, thereby further increasing financial constraints for adaptation, particularly for developing and least developed countries (*medium confidence*). {Figure TS.7, 1.4, 2.6, 3.6, 4.7, Figure 4.30, 5.14, 7.4, 8.4, Table 8.6, 9.4, 9.9, 9.11, 10.5, 12.5, 13.3, 13.11, Box 14.4, 15.6, 16.2, 16.4, Figure 16.8, Table 16.4, 17.4, 18.1, CCP2.4, CCP5.4, CCP6.3, CCB FINANCE}
- C.3.3** Many natural systems are near the hard limits of their natural adaptation capacity and additional systems will reach limits with increasing global warming (*high confidence*). Ecosystems already reaching or surpassing hard adaptation limits include some warm-water coral reefs, some coastal wetlands, some rainforests, and some polar and mountain ecosystems (*high confidence*). Above 1.5°C global warming level, some Ecosystem-based Adaptation measures will lose their effectiveness in providing benefits to people as these ecosystems will reach hard adaptation limits (*high confidence*). (Figure SPM.4) {1.4, 2.4, 2.6, 3.4, 3.6, 9.6, Box 11.2, 13.4, 14.5, 15.5, 16.4, 16.6, 17.2, CCP1.2, CCP5.2, CCP6.3, CCP7.3, CCB SLR}
- C.3.4** In human systems, some coastal settlements face soft adaptation limits due to technical and financial difficulties of implementing coastal protection (*high confidence*). Above 1.5°C global warming level, limited freshwater resources pose potential hard limits for Small Islands and for regions dependent on glacier and snow-melt (*medium confidence*). By 2°C global warming level, soft limits are projected for multiple staple crops in many growing areas, particularly in tropical regions (*high confidence*). By 3°C global warming level, soft limits are projected for some water management measures for many regions, with hard limits projected for parts of Europe (*medium confidence*). Transitioning from incremental to transformational adaptation can help overcome soft adaptation limits (*high confidence*). {1.4, 4.7, 5.4, 5.8, 7.2, 7.3, 8.4, Table 8.6, 9.8, 10.4, 12.5, 13.2, 13.6, 16.4, 17.2, CCP1.3, Box CCP1.1, CCP2.3, CCP3.3, CCP4.4, CCP5.3, CCB SLR}
- C.3.5** Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. Losses and damages are unequally distributed across systems, regions and sectors and are not comprehensively addressed by current financial, governance and institutional arrangements, particularly in vulnerable developing countries. With increasing global warming, losses and damages increase and become increasingly difficult to avoid, while strongly concentrated among the poorest vulnerable populations. (*high confidence*) {1.4, 2.6, 3.4, 3.6, 6.3, Figure 6.4, 8.4, 13.2, 13.7, 13.10, 17.2, CCP2.3, CCP4.4, CCB LOSS, CCB SLR, CWGB ECONOMIC}

⁴⁶ Climate literacy encompasses being aware of climate change, its anthropogenic causes and implications.

Avoiding Maladaptation

- C.4** There is increased evidence of maladaptation¹⁵ across many sectors and regions since the AR5. Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities. Maladaptation can be avoided by flexible, multi-sectoral, inclusive and long-term planning and implementation of adaptation actions with benefits to many sectors and systems. (*high confidence*) {1.3, 1.4, 2.6, Box 2.2, 3.2, 3.6, 4.6, 4.7, Box 4.3, Box 4.5, Figure 4.29, 5.6, 5.13, 8.2, 8.3, 8.4, 8.6, 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, Box 9.5, Box 9.8, Box 9.9, Box 11.6, 13.11, 13.3, 13.4, 13.5, 14.5, 15.5, 15.6, 16.3, 17.2, 17.3, 17.4, 17.5, 17.6, CCP2.3, CCP2.3, CCP5.4, CCB DEEP, CCB NATURAL, CCB SLR, CWGB BIOECONOMY}
- C.4.1** Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation if long-term impacts of the adaptation option and long-term adaptation commitment are not taken into account (*high confidence*). The implementation of these maladaptive actions can result in infrastructure and institutions that are inflexible and/or expensive to change (*high confidence*). For example, seawalls effectively reduce impacts to people and assets in the short-term but can also result in lock-ins and increase exposure to climate risks in the long-term unless they are integrated into a long-term adaptive plan (*high confidence*). Adaptation integrated with development reduces lock-ins and creates opportunities (e.g., infrastructure upgrading) (*medium confidence*). {1.4, 3.4, 3.6, 10.4, 11.7, Box 11.6, 13.2, 17.2, 17.5, 17.6, CCP 2.3, CCB DEEP, CCB SLR}
- C.4.2** Biodiversity and ecosystem resilience to climate change are decreased by maladaptive actions, which also constrain ecosystem services. Examples of these maladaptive actions for ecosystems include fire suppression in naturally fire-adapted ecosystems or hard defences against flooding. These actions reduce space for natural processes and represent a severe form of maladaptation for the ecosystems they degrade, replace or fragment, thereby reducing their resilience to climate change and the ability to provide ecosystem services for adaptation. Considering biodiversity and autonomous adaptation in long-term planning processes reduces the risk of maladaptation. (*high confidence*) {2.4, 2.6, Table 2.7, 3.4, 3.6, 4.7, 5.6, 5.13, Table 5.21, Table 5.23, Box 11.2, 13.2, Box 13.2, 17.2, 17.5, CCP5.4}
- C.4.3** Maladaptation especially affects marginalised and vulnerable groups adversely (e.g., Indigenous Peoples, ethnic minorities, low-income households, informal settlements), reinforcing and entrenching existing inequities. Adaptation planning and implementation that do not consider adverse outcomes for different groups can lead to maladaptation, increasing exposure to risks, marginalising people from certain socioeconomic or livelihood groups, and exacerbating inequity. Inclusive planning initiatives informed by cultural values, Indigenous knowledge, local knowledge, and scientific knowledge can help prevent maladaptation. (*high confidence*) (Figure SPM.4) {2.6, 3.6, 4.3, 4.6, 4.8, 5.12, 5.13, 5.14, 6.1, Box 7.1, 8.4, 11.4, 12.5, Box 13.2, 14.4, Box 14.1, 17.2, 17.5, 18.2, 17.2, CCP2.4}
- C.4.4** To minimize maladaptation, multi-sectoral, multi-actor and inclusive planning with flexible pathways encourages low-regret⁴⁷ and timely actions that keep options open, ensure benefits in multiple sectors and systems and indicate the available solution space for adapting to long-term climate change (*very high confidence*). Maladaptation is also minimized by planning that accounts for the time it takes to adapt (*high confidence*), the uncertainty about the rate and magnitude of climate risk (*medium confidence*) and a wide range of potentially adverse consequences of adaptation actions (*high confidence*). {1.4, 3.6, 5.12, 5.13, 5.14, 11.6, 11.7, 17.3, 17.6, CCP2.3, CCP2.4, CCP5.4, CCB DEEP, CCB SLR}

Enabling Conditions

- C.5** Enabling conditions are key for implementing, accelerating and sustaining adaptation in human systems and ecosystems. These include political commitment and follow-through, institutional frameworks, policies and instruments with clear goals and priorities, enhanced knowledge on impacts and solutions, mobilization of and access to adequate financial resources, monitoring and evaluation, and inclusive governance processes. (*high confidence*) {1.4, 2.6, 3.6, 4.8, 6.4, 7.4, 8.5, 9.4, 10.5, 11.4, 11.7, 12.5, 13.11, 14.7, 15.6, 17.4, 18.4, CCP2.4, CCP5.4, CCB FINANCE, CCB INDIG}
- C.5.1** Political commitment and follow-through across all levels of government accelerate the implementation of adaptation actions (*high confidence*). Implementing actions can require large upfront investments of human, financial and technological resources (*high confidence*), whilst some benefits could only become visible in the next decade or beyond (*medium confidence*). Accelerating commitment and follow-through is promoted by rising public awareness, building business cases for adaptation, accountability and transparency mechanisms, monitoring and evaluation of adaptation progress, social movements, and climate-related litigation in some regions (*medium confidence*). {3.6, 4.8, 5.8, 6.4, 8.5, 9.4, 11.7, 12.5, 13.11, 17.4, 17.5, 18.4, CCP2.4, CCB COVID}

⁴⁷ From AR5, an option that would generate net social and/or economic benefits under current climate change and a range of future climate change scenarios, and represent one example of robust strategies.

- C.5.2** Institutional frameworks, policies and instruments that set clear adaptation goals and define responsibilities and commitments and that are coordinated amongst actors and governance levels, strengthen and sustain adaptation actions (*very high confidence*). Sustained adaptation actions are strengthened by mainstreaming adaptation into institutional budget and policy planning cycles, statutory planning, monitoring and evaluation frameworks and into recovery efforts from disaster events (*high confidence*). Instruments that incorporate adaptation such as policy and legal frameworks, behavioural incentives, and economic instruments that address market failures, such as climate risk disclosure, inclusive and deliberative processes strengthen adaptation actions by public and private actors (*medium confidence*). {1.4, 3.6, 4.8, 5.14, 6.3, 6.4, 7.4, 9.4, 10.4, 11.7, Box 11.6, Table 11.17, 13.10, 13.11, 14.7, 15.6, 17.3, 17.4, 17.5, 17.6, 18.4, CCP2.4, CCP5.4, CCP6.3, CCB DEEP}
- C.5.3** Enhancing knowledge on risks, impacts, and their consequences, and available adaptation options promotes societal and policy responses (*high confidence*). A wide range of top-down, bottom-up and co-produced processes and sources can deepen climate knowledge and sharing, including capacity building at all scales, educational and information programmes, using the arts, participatory modelling and climate services, Indigenous knowledge and local knowledge and citizen science (*high confidence*). These measures can facilitate awareness, heighten risk perception and influence behaviours (*high confidence*). {1.3, 3.6, 4.8, 5.9, 5.14, 6.4, Table 6.8, 7.4, 9.4, 10.5, 11.1, 11.7, 12.5, 13.9, 13.11, 14.3, 15.6, 15.6, 17.4, 18.4, CCP2.4.1, CCB INDIG}
- C.5.4** With adaptation finance needs estimated to be higher than those presented in AR5, enhanced mobilization of and access to financial resources are essential for implementation of adaptation and to reduce adaptation gaps (*high confidence*). Building capacity and removing some barriers to accessing finance is fundamental to accelerate adaptation, especially for vulnerable groups, regions and sectors (*high confidence*). Public and private finance instruments include inter alia grants, guarantee, equity, concessional debt, market debt, and internal budget allocation as well as savings in households and insurance. Public finance is an important enabler of adaptation (*high confidence*). Public mechanisms and finance can leverage private sector finance for adaptation by addressing real and perceived regulatory, cost and market barriers, for example via public-private partnerships (*high confidence*). Financial and technological resources enable effective and ongoing implementation of adaptation, especially when supported by institutions with a strong understanding of adaptation needs and capacity (*high confidence*). {4.8, 5.14, 6.4, Table 6.10, 7.4, 9.4, Table 11.17, 12.5, 13.11, 15.6, 17.4, 18.4, Box 18.9, CCP5.4, CCB FINANCE}
- C.5.5** Monitoring and evaluation (M&E) of adaptation are critical for tracking progress and enabling effective adaptation (*high confidence*). M&E implementation is currently limited (*high confidence*) but has increased since AR5 at local and national levels. Although most of the monitoring of adaptation is focused towards planning and implementation, the monitoring of outcomes is critical for tracking the effectiveness and progress of adaptation (*high confidence*). M&E facilitates learning on successful and effective adaptation measures, and signals when and where additional action may be needed. M&E systems are most effective when supported by capacities and resources and embedded in enabling governance systems (*high confidence*). {1.4, 2.6, 6.4, 7.4, 11.7, 11.8, 13.2, 13.11, 17.5, 18.4, CCP2.4, CCB DEEP, CCB ILLNESS, CCB NATURAL, CCB PROGRESS}
- C.5.6** Inclusive governance that prioritises equity and justice in adaptation planning and implementation leads to more effective and sustainable adaptation outcomes (*high confidence*). Vulnerabilities and climate risks are often reduced through carefully designed and implemented laws, policies, processes, and interventions that address context specific inequities such as based on gender, ethnicity, disability, age, location and income (*high confidence*). These approaches, which include multi-stakeholder co-learning platforms, transboundary collaborations, community-based adaptation and participatory scenario planning, focus on capacity-building, and meaningful participation of the most vulnerable and marginalised groups, and their access to key resources to adapt (*high confidence*). {1.4, 2.6, 3.6, 4.8, 5.4, 5.8, 5.9, 5.13, 6.4, 7.4, 8.5, 11.8, 12.5, 13.11, 14.7, 15.5, 15.7, 17.3, 17.5, 18.4, CCP2.4, CCP5.4, CCP6.4, CCB GENDER, CCB HEALTH, CCB INDIG}

D: Climate Resilient Development

Climate resilient development integrates adaptation measures and their enabling conditions (Section C) with mitigation to advance sustainable development for all. Climate resilient development involves questions of equity and system transitions in land, ocean and ecosystems; urban and infrastructure; energy; industry; and society and includes adaptations for human, ecosystem and planetary health. Pursuing climate resilient development focuses on both where people and ecosystems are co-located as well as the protection and maintenance of ecosystem function at the planetary scale. Pathways for advancing climate resilient development are development trajectories that successfully integrate mitigation and adaptation actions to advance sustainable development. Climate resilient development pathways may be temporarily coincident with any RCP and SSP scenario used throughout AR6, but do not follow any particular scenario in all places and over all time.

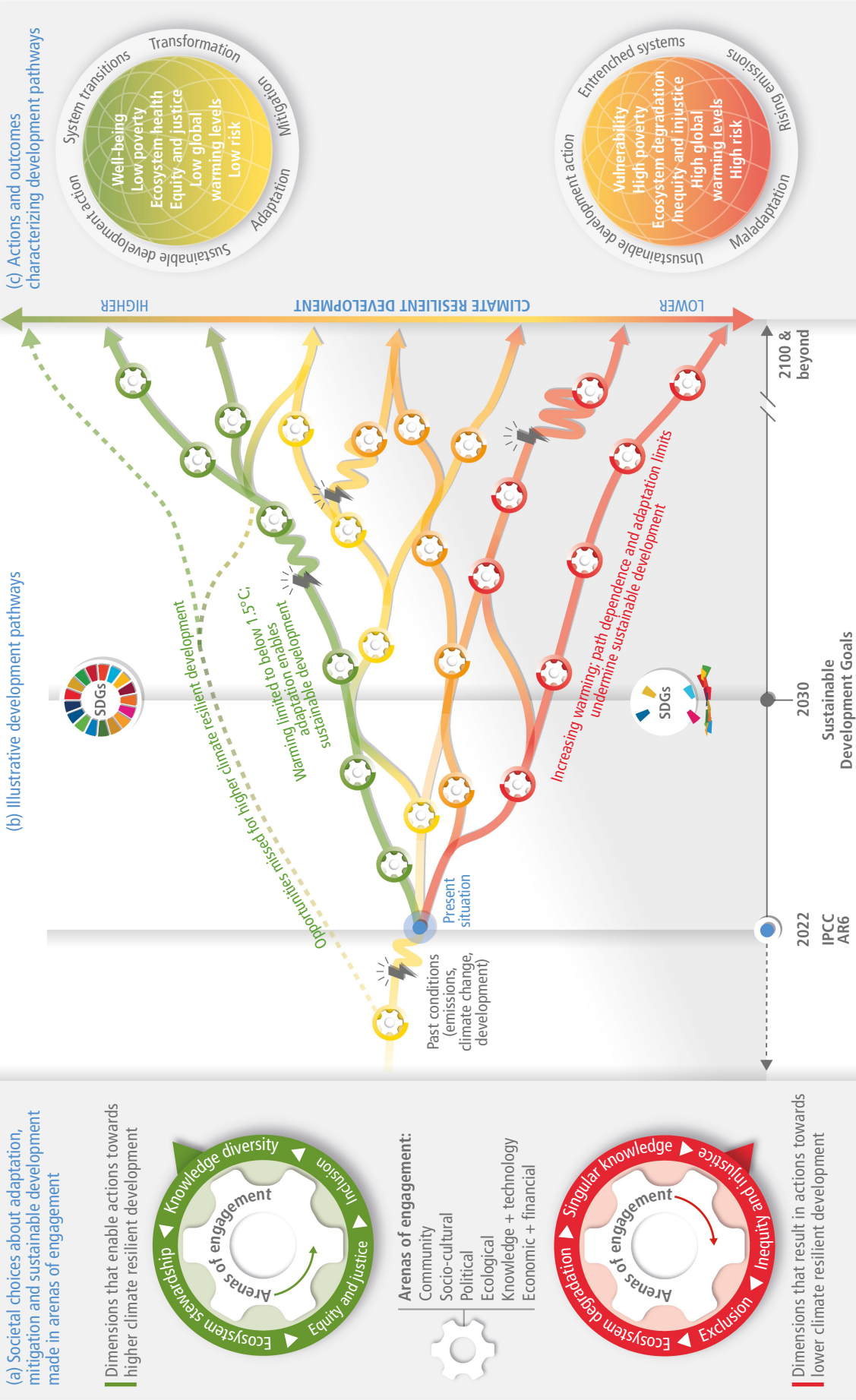
Conditions for Climate Resilient Development

- D.1 Evidence of observed impacts, projected risks, levels and trends in vulnerability, and adaptation limits, demonstrate that worldwide climate resilient development action is more urgent than previously assessed in AR5. Comprehensive, effective, and innovative responses can harness synergies and reduce trade-offs between adaptation and mitigation to advance sustainable development. (*very high confidence*)** {2.6, 3.4, 3.6, 4.2, 4.6, 7.2, 7.4, 8.3, 8.4, 9.3, 10.6, 13.3, 13.8, 13.10, 14.7, 17.2, 18.3, Box 18.1, Figure 18.1, Table 18.5}
- D.1.1** There is a rapidly narrowing window of opportunity to enable climate resilient development. Multiple climate resilient development pathways are still possible by which communities, the private sector, governments, nations and the world can pursue climate resilient development – each involving and resulting from different societal choices influenced by different contexts and opportunities and constraints on system transitions. Climate resilient development pathways are progressively constrained by every increment of warming, in particular beyond 1.5°C, social and economic inequalities, the balance between adaptation and mitigation varying by national, regional and local circumstances and geographies, according to capabilities including resources, vulnerability, culture and values, past development choices leading to past emissions and future warming scenarios, bounding the climate resilient development pathways remaining, and the ways in which development trajectories are shaped by equity, and social and climate justice. (*very high confidence*) {Figure TS.14d, 2.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 9.4, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, 18.5, CCP2.3, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP7.5}
- D.1.2** Opportunities for climate resilient development are not equitably distributed around the world (*very high confidence*). Climate impacts and risks exacerbate vulnerability and social and economic inequities and consequently increase persistent and acute development challenges, especially in developing regions and sub-regions, and in particularly exposed sites, including coasts, small islands, deserts, mountains and polar regions. This in turn undermines efforts to achieve sustainable development, particularly for vulnerable and marginalized communities (*very high confidence*). {2.5, 4.4, 4.7, 6.3, Box 6.4, Figure 6.5, 9.4, Table 18.5, CCP2.2, CCP3.2, CCP3.3, CCP5.4, CCP6.2, CCB HEALTH, CWGB URBAN}
- D.1.3** Embedding effective and equitable adaptation and mitigation in development planning can reduce vulnerability, conserve and restore ecosystems, and enable climate resilient development. This is especially challenging in localities with persistent development gaps and limited resources (*high confidence*). Dynamic trade-offs and competing priorities exist between mitigation, adaptation, and development. Integrated and inclusive system-oriented solutions based on equity and social and climate justice reduce risks and enable climate resilient development (*high confidence*). {1.4, 2.6, Box 2.2, 3.6, 4.7, 4.8, Box 4.5, Box 4.8, 5.13, 7.4, 8.5, 9.4, Box 9.3, 10.6, 12.5, 12.6, 13.3, 13.4, 13.10, 13.11, 14.7, 18.4, CCB DEEP, CCP2, CCP5.4, CCB HEALTH, SRCCL}

Enabling Climate Resilient Development

- D.2 Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritise risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors and timeframes (*very high confidence*). Climate resilient development is facilitated by international cooperation and by governments at all levels working with communities, civil society, educational bodies, scientific and other institutions, media, investors and businesses; and by developing partnerships with traditionally marginalised groups, including women, youth, Indigenous Peoples, local communities and ethnic minorities (*high confidence*). These partnerships are most effective when supported by enabling political leadership, institutions, resources, including finance, as well as climate services, information and decision support tools (*high confidence*). (Figure SPM.5)** {1.3, 1.4, 1.5, 2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.4, 17.6, 18.4, 18.5, CCP2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB GENDER, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}
- D.2.1** Climate resilient development is advanced when actors work in equitable, just and enabling ways to reconcile divergent interests, values and worldviews, toward equitable and just outcomes (*high confidence*). These practices build on diverse knowledges about climate risk and chosen development pathways account for local, regional and global climate impacts, risks, barriers and opportunities (*high confidence*). Structural vulnerabilities to climate change can be reduced through carefully designed and implemented legal, policy, and process interventions from the local to global that address inequities based on gender, ethnicity, disability, age, location and income (*very high confidence*). This includes rights-based approaches that focus on capacity-building, meaningful participation of the most vulnerable groups, and their access to key resources, including financing, to reduce risk and adapt (*high confidence*). Evidence shows that climate resilient development processes link scientific, Indigenous, local, practitioner and other forms of knowledge, and are more effective and sustainable because they are locally appropriate and lead to more legitimate, relevant and effective actions (*high confidence*).

There is a rapidly narrowing window of opportunity to enable climate resilient development



Narrowing window of opportunity for higher CRD

Illustrative climatic or non-climatic shock, e.g. COVID-19, drought or floods, that disrupts the development pathway

Figure SPM.5 | Climate resilient development (CRD) is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. This figure builds on Figure SPM.9 in AR5 WGII (depicting climate resilient pathways) by describing how CRD pathways are the result of cumulative societal choices and actions within multiple arenas.

Panel (a) Societal choices towards higher CRD (**green cog**) or lower CRD (**red cog**) result from interacting decisions and actions by diverse government, private sector and civil society actors, in the context of climate risks, adaptation limits and development gaps. These actors engage with adaptation, mitigation and development actions in political, economic and financial, ecological, socio-cultural, knowledge and technology, and community arenas from local to international levels. Opportunities for climate resilient development are not equitably distributed around the world.

Panel (b) Cumulatively, societal choices, which are made continuously, shift global development pathways towards higher (**green**) or lower (**red**) climate resilient development. Past conditions (past emissions, climate change and development) have already eliminated some development pathways towards higher CRD (**dashed green line**).

Panel (c) Higher CRD is characterised by outcomes that advance sustainable development for all. Climate resilient development is progressively harder to achieve with global warming levels beyond 1.5°C. Inadequate progress towards the Sustainable Development Goals (SDGs) by 2030 reduces climate resilient development prospects. There is a narrowing window of opportunity to shift pathways towards more climate resilient development futures as reflected by the adaptation limits and increasing climate risks, considering the remaining carbon budgets. (Figure SPM.2, Figure SPM.3) {Figure TS.14b, 2.6, 3.6, 7.2, 7.3, 7.4, 8.3, 8.4, 8.5, 16.4, 16.5, 17.3, 17.4, 17.5, 18.1, 18.2, 18.3, 18.4, Box 18.1, Figure 18.1, Figure 18.2, Figure 18.3, CCB COVID, CCB GENDER, CCB HEALTH, CCB INDIG, CCB SLR, WGI AR6 Table SPM.1, WGI AR6 Table SPM.2, SR1.5 Figure SPM.1}

Pathways towards climate resilient development overcome jurisdictional and organizational barriers, and are founded on societal choices that accelerate and deepen key system transitions (*very high confidence*). Planning processes and decision analysis tools can help identify ‘low regrets’ options⁴⁷ that enable mitigation and adaptation in the face of change, complexity, deep uncertainty and divergent views (*medium confidence*). {1.3, 1.4, 1.5, 2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, Box 8.7, 9.4, Box 9.2, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.2.2 Inclusive governance contributes to more effective and enduring adaptation outcomes and enables climate resilient development (*high confidence*). Inclusive processes strengthen the ability of governments and other stakeholders to jointly consider factors such as the rate and magnitude of change and uncertainties, associated impacts, and timescales of different climate resilient development pathways given past development choices leading to past emissions and scenarios of future global warming (*high confidence*). Associated societal choices are made continuously through interactions in arenas of engagement from local to international levels. The quality and outcome of these interactions helps determine whether development pathways shift towards or away from climate resilient development (*medium confidence*). (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2, 18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB GENDER, CCB HEALTH, CCB INDIG}

D.2.3 Governance for climate resilient development is most effective when supported by formal and informal institutions and practices that are well-aligned across scales, sectors, policy domains and timeframes. Governance efforts that advance climate resilient development account for the dynamic, uncertain and context-specific nature of climate-related risk, and its interconnections with non-climate risks. Institutions⁴⁸ that enable climate resilient development are flexible and responsive to emergent risks and facilitate sustained and timely action. Governance for climate resilient development is enabled by adequate and appropriate human and technological resources, information, capacities and finance. (*high confidence*) {2.7, 3.6, 4.8, 5.14, 6.3, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2, 18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB GENDER, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

Climate Resilient Development for Natural and Human Systems

D.3 Interactions between changing urban form, exposure and vulnerability can create climate change-induced risks and losses for cities and settlements. However, the global trend of urbanisation also offers a critical opportunity in the near-term, to advance climate resilient development (*high confidence*). Integrated, inclusive planning and investment in everyday decision-making about urban infrastructure, including social, ecological and grey/physical infrastructures, can significantly increase the adaptive capacity of urban and rural settlements. Equitable outcomes contributes to multiple benefits for health and well-being and ecosystem services, including for Indigenous Peoples, marginalised and vulnerable communities (*high confidence*). Climate resilient development in urban areas also supports adaptive capacity in more rural places through maintaining peri-urban supply chains of goods and services and financial flows (*medium confidence*). Coastal cities and settlements play an especially important role in advancing climate resilient development (*high confidence*). {6.2, 6.3, Table 6.6, 7.4, 8.6, Box 9.8, 18.3, CCP2.1, CCP2.2, CCP6.2, CWGB URBAN}

⁴⁸ Institutions: Rules, norms and conventions that guide, constrain or enable human behaviours and practices. Institutions can be formally established, for instance through laws and regulations, or informally established, for instance by traditions or customs. Institutions may spur, hinder, strengthen, weaken or distort the emergence, adoption and implementation of climate action and climate governance.

- D.3.1** Taking integrated action for climate resilience to avoid climate risk requires urgent decision making for the new built environment and retrofitting existing urban design, infrastructure and land use. Based on socioeconomic circumstances, adaptation and sustainable development actions will provide multiple benefits including for health and well-being, particularly when supported by national governments, non-governmental organisations and international agencies that work across sectors in partnerships with local communities. Equitable partnerships between local and municipal governments, the private sector, Indigenous Peoples, local communities, and civil society can, including through international cooperation, advance climate resilient development by addressing structural inequalities, insufficient financial resources, cross-city risks and the integration of Indigenous knowledge and local knowledge. (*high confidence*) {6.2, 6.3, 6.4, Table 6.6, 7.4, 8.5, 9.4, 10.5, 12.5, 17.4, Table 17.8, 18.2, Box 18.1, CCP2.4, CCB FINANCE, CCB GENDER, CCB INDIG, CWGB URBAN}
- D.3.2** Rapid global urbanisation offers opportunities for climate resilient development in diverse contexts from rural and informal settlements to large metropolitan areas (*high confidence*). Dominant models of energy intensive and market-led urbanisation, insufficient and misaligned finance and a predominant focus on grey infrastructure in the absence of integration with ecological and social approaches, risks missing opportunities for adaptation and locking in maladaptation (*high confidence*). Poor land use planning and siloed approaches to health, ecological and social planning also exacerbates, vulnerability in already marginalised communities (*medium confidence*). Urban climate resilient development is observed to be more effective if it is responsive to regional and local land use development and adaptation gaps, and addresses the underlying drivers of vulnerability (*high confidence*). The greatest gains in well-being can be achieved by prioritizing finance to reduce climate risk for low-income and marginalized residents including people living in informal settlements (*high confidence*). {5.14, 6.1, 6.2, 6.3, 6.4, 6.5, Figure 6.5, Table 6.6, 7.4, 8.5, 8.6, 9.8, 9.9, 10.4, Table 17.8, 18.2, CCP2.2, CCP5.4, CCB HEALTH, CWGB URBAN}
- D.3.3** Urban systems are critical, interconnected sites for enabling climate resilient development, especially at the coast. Coastal cities and settlements play a key role in moving toward higher climate resilient development given firstly, almost 11% of the global population – 896 million people – lived within the Low Elevation Coastal Zone⁴⁹ in 2020, potentially increasing to beyond 1 billion people by 2050, and these people, and associated development and coastal ecosystems, face escalating climate compounded risks, including sea level rise. Secondly, these coastal cities and settlements make key contributions to climate resilient development through their vital role in national economies and inland communities, global trade supply chains, cultural exchange, and centres of innovation. (*high confidence*) {6.1, 6.2, 6.4, Table 6.6, Box 15.2, SMCCP Table 2.1, CCP2.2, CCP2.4, CCB SLR, XWGB URBAN, SROCC Chapter 4}
- D.4** **Safeguarding biodiversity and ecosystems is fundamental to climate resilient development, in light of the threats climate change poses to them and their roles in adaptation and mitigation (*very high confidence*).** Recent analyses, drawing on a range of lines of evidence, suggest that maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems (*high confidence*). {2.4, 2.5, 2.6, 3.4, 3.5, 3.6, Box 3.4, 12.5, 13.3, 13.4, 13.5, 13.10, CCB INDIG, CCB NATURAL}
- D.4.1** Building the resilience of biodiversity and supporting ecosystem integrity⁵⁰ can maintain benefits for people, including livelihoods, human health and well-being and the provision of food, fibre and water, as well as contributing to disaster risk reduction and climate change adaptation and mitigation. {2.2, 2.5, 2.6, Table 2.6, Table 2.7, 3.5, 3.6, 5.8, 5.13, 5.14, Box 5.11, 12.5, CCP5.4, CCB COVID, CCB GENDER, CCB ILLNESS, CCB INDIG, CCB MIGRATE, CCB NATURAL}
- D.4.2** Protecting and restoring ecosystems is essential for maintaining and enhancing the resilience of the biosphere (*very high confidence*). Degradation and loss of ecosystems is also a cause of greenhouse gas emissions and is at increasing risk of being exacerbated by climate change impacts, including droughts and wildfire (*high confidence*). Climate resilient development avoids adaptation and mitigation measures that damage ecosystems (*high confidence*). Documented examples of adverse impacts of land-based measures intended as mitigation, when poorly implemented, include afforestation of grasslands, savannas and peatlands, and risks from bioenergy crops at large scale to water supply, food security and biodiversity (*high confidence*). {2.4, 2.5, Box 2.2, 3.4, 3.5, Box 3.4, Box 9.3, CCP7.3, CCB NATURAL, CWGB BIOECONOMY}

49 LECZ, coastal areas below 10 m of elevation above sea level that are hydrologically connected to the sea.

50 Ecosystem integrity refers to the ability of ecosystems to maintain key ecological processes, recover from disturbance, and adapt to new conditions.

- D.4.3** Biodiversity and ecosystem services have limited capacity to adapt to increasing global warming levels, which will make climate resilient development progressively harder to achieve beyond 1.5°C warming (*very high confidence*). Consequences of current and future global warming for climate resilient development include reduced effectiveness of Ecosystem-based Adaptation and approaches to climate change mitigation based on ecosystems and amplifying feedbacks to the climate system (*high confidence*). {Figure TS.14d, 2.4, 2.5, 2.6, 3.4, Box 3.4, 3.5, 3.6, Table 5.2, 12.5, 13.2, 13.3, 13.10, 14.5, 14.5, Box 14.3, 15.3, 17.3, 17.6, CCP5.3, CCP5.4, CCB EXTREMES, CCB ILLNESS, CCB NATURAL, CCB SLR, SR1.5, SRCCL, SROCC}

Achieving Climate Resilient Development

- D.5** It is unequivocal that climate change has already disrupted human and natural systems. Past and current development trends (past emissions, development and climate change) have not advanced global climate resilient development (*very high confidence*). Societal choices and actions implemented in the next decade determine the extent to which medium- and long-term pathways will deliver higher or lower climate resilient development (*high confidence*). Importantly climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline, especially if 1.5°C global warming is exceeded in the near-term (*high confidence*). These prospects are constrained by past development, emissions and climate change, and enabled by inclusive governance, adequate and appropriate human and technological resources, information, capacities and finance (*high confidence*). {Figure TS.14d, 1.2, 1.4, 1.5, 2.6, 2.7, 3.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 8.5, 8.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 13.11, 14.7, 15.3, 15.6, 15.7, 16.2, 16.4, 16.5, 16.6, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP6.4, CCP7.5, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}
- D.5.1** Climate resilient development is already challenging at current global warming levels (*high confidence*). The prospects for climate resilient development will be further limited if global warming levels exceeds 1.5°C (*high confidence*) and not be possible in some regions and sub-regions if the global warming level exceeds 2°C (*medium confidence*). Climate resilient development is most constrained in regions/subregions in which climate impacts and risks are already advanced, including low-lying coastal cities and settlements, small islands, deserts, mountains and polar regions (*high confidence*). Regions and subregions with high levels of poverty, water, food and energy insecurity, vulnerable urban environments, degraded ecosystems and rural environments, and/or few enabling conditions, face many non-climate challenges that inhibit climate resilient development which are further exacerbated by climate change (*high confidence*). {Figure TS.14d, 1.2, Box 6.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, CCP2.3, CCP3.4, CCP4.4, CCP5.3, Table CCP5.2, CCP6.3, CCP7.5}
- D.5.2** Inclusive governance, investment aligned with climate resilient development, access to appropriate technology and rapidly scaled-up finance, and capacity building of governments at all levels, the private sector and civil society enable climate resilient development. Experience shows that climate resilient development processes are timely, anticipatory, integrative, flexible and action focused. Common goals and social learning build adaptive capacity for climate resilient development. When implementing adaptation and mitigation together, and taking trade-offs into account, multiple benefits and synergies for human well-being as well as ecosystem and planetary health can be realised. Prospects for climate resilient development are increased by inclusive processes involving local knowledge and Indigenous Knowledge as well as processes that coordinate across risks and institutions. Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for vulnerable regions, sectors and groups. (*high confidence*) (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}
- D.5.3** The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (*very high confidence*) {1.2, 1.4, 1.5, 16.2, Table SM16.24, 16.4, 16.5, 16.6, 17.4, 17.5, 17.6, 18.3, 18.4, 18.5, CCB DEEP, CWGB URBAN, WGI AR6 SPM, SROCC SPM, SRCCL SPM}

Science-Based Guidelines for Managing Northern Goshawk Breeding Areas in Coastal British Columbia

Special Issue

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Abstract

Northern Goshawks (*Accipiter gentilis laingi*) have been recognized as a species of management concern in western North America for over 20 years. One of the most significant factors threatening Northern Goshawk populations in coastal British Columbia is the loss and fragmentation of structurally old and mature forests they use for breeding, foraging, and roosting. The goal of this report is to provide science-based guidelines for qualified environmental professionals to assist in their decision-making processes concerning Northern Goshawk habitat management in coastal British Columbia. These guidelines were previously unavailable or inconsistent and did not provide a thorough review of the scientific literature. The best management practices presented here are intended for use by qualified environmental professionals and managers when undertaking industrial activities, primarily forestry, around Northern Goshawk breeding areas within coastal British Columbia.

KEYWORDS: *Accipiter gentilis laingi*; best management practices; breeding area; breeding habitat; coastal British Columbia; disturbance; foraging habitat; forest management; occupancy; management guidelines; nesting habitat; northern goshawk; post-fledging area; reserve size; risk; science guidelines; territory; timing restrictions

Location of accompanying documentation

Further information on individual studies, projects, or supplemental information used in this report is available upon request directly from the report authors.

SCIENCE-BASED
GUIDELINES
FOR MANAGING
NORTHERN GOSHAWK
BREEDING AREAS

McClaren, Mahon,
Doyle, & Harrower

Table of Contents

Abstract	1
Executive Summary	4
1 Introduction.....	6
1.1 Distribution	7
1.2 Ranking status	8
1.3 Regulatory framework.....	9
1.3.1 International	9
1.3.2 Federal.....	9
1.3.3 Provincial (British Columbia)	10
2 Scope and Objectives	10
2.1 Science-based management.....	11
3 Long-term Studies on Coastal Goshawks.....	13
3.1 Vancouver Island	13
3.2 Haida Gwaii.....	15
3.3 Summary of other coastal goshawk study locations	16
3.3.1 Mainland coastal British Columbia.....	16
3.3.2 United States	16
3.4 Analyses of coastal goshawk data to support these guidelines.....	16
4 Breeding Ecology of Coastal Goshawks	17
4.1 Individual age	17
4.2 Breeding chronology.....	17
4.3 Productivity, occupancy, and survival	18
4.4 Habitat characteristics	19
4.5 Nest tree and breeding area spacing patterns	20
4.6 Foraging.....	20
5 Coastal Goshawk Territory Components	21
5.1 Nest site and nest area characteristics	25
5.2 Post-fledging area characteristics and fledgling movements.....	30
5.3 Estimating the size of breeding areas in coastal British Columbia	32
5.4 Home range and foraging habitat.....	34
6 Responses of Coastal Goshawks to Breeding Area Disturbance	39
6.1 Direct disturbance.....	39
6.2 Indirect disturbance from habitat alteration and loss within breeding areas	41
7 Other Sources of Variation in Breeding Area Occupancy and Reproduction	45
7.1 Individual quality	45

7.2 Annual and longer-term weather patterns.....	46
7.3 Prey, predators, and competitors.....	46
8 Best Management Practices for Coastal Goshawk Breeding Areas	47
8.1 Summary of best management practices for coastal goshawk breeding areas ...	49
8.2 Defining the breeding area	50
8.3 Reserve design	52
8.4 Minimizing direct disturbance: timing restrictions	53
8.5 Managing multiple breeding areas	54
8.6 Foraging area considerations	54
9 Strategic and Operational Planning Considerations.....	56
9.1 Co-location of breeding area reserves	56
9.2 Windthrow considerations in reserve design.....	59
9.3 Habitat quality evaluation: operational and strategic considerations	59
9.4 Enhancing forest structure to promote goshawk habitat characteristics	60
10 Knowledge Gaps and Key Research Questions.....	61
11 Data Management.....	64
Acknowledgements.....	65
Notes	66
References.....	67
Appendix 1: Glossary	79
Appendix 2: Key to Abbreviations of Biogeoclimatic Subzones and Tree Species.....	83
Appendix 3: Updated Analyses for Coastal Best Management Practices: Detailed Methodology	84
Appendix 4: Breeding Area Delineation and Monitoring.....	87
Author Information.....	91

Executive Summary

The two subspecies of Northern Goshawks (*Accipiter gentilis atricapillus*, *Accipiter gentilis laingi*) occurring in western North America have been a management concern for over 20 years. One of the most significant factors threatening Northern Goshawk populations in British Columbia is the loss and fragmentation (i.e., smaller patch sizes) of the structurally old and mature forests used by Northern Goshawks for breeding, foraging, and security cover (roosting). The coastal goshawk subspecies (*A. g. laingi*), which is the focus of this report, is provincially red-listed and federally listed as threatened as a result of habitat loss, small population size, and their limited range extent. Goshawks within interior British Columbia forests are not listed under provincial or federal species-at-risk designations.

No standardized science-based guidelines have been available to advise qualified environmental professionals in their decisions concerning coastal goshawk habitat management in British Columbia. As a result, management strategies around coastal goshawk nests have been inconsistently applied, and many strategies were not informed by the best available science. Existing government management guidelines, notably the *Identified Wildlife Management Strategy*, were adapted from guidelines developed in other regions, where aspects of goshawk ecology and forest management differ from those in coastal British Columbia. In this report, we propose a set of best management practices for use by qualified environmental professionals and managers when undertaking industrial activities, primarily forestry, around coastal goshawk breeding areas. These practices are tailored specifically to goshawk ecology and forest management systems used in coastal British Columbia, and some aspects may not be applicable to other ecosystems.

These coastal best management practices were developed by a team of professional biologists using a science-based management approach. The two main tenets of this approach are: (1) to maximize the use of local data to guide management recommendations, and (2) to present a range of management options (along with probable consequences) from which qualified environmental professionals can choose on the basis of competing resource values and different risk tolerances. Local data used included two long-term inventory, monitoring, and research projects on coastal goshawks in British Columbia—one on Vancouver Island (1994–2012) and the other on Haida Gwaii (1995–ongoing). These best management practices are consistent with the Government of Canada's 2003 *Framework for the Application of Precaution in Science-based Decision Making about Risk*.

The practices outlined here are directed at maintaining habitat conditions that can support long-term occupancy and reproductive success within coastal goshawk breeding areas. Breeding areas are the primary ecological unit for all goshawk breeding activities including courtship, nesting, fledging, and the rearing of fledglings before dispersal. These areas include nest trees (historic, current, and potential future ones), plucking posts, roosts, and post-fledging areas associated with each nest tree over multiple years. Coastal goshawks exhibit strong fidelity to established breeding areas and may occupy them for decades if suitable conditions persist.

These best management practices include the following key recommendations.

Stand Context

- Once an active breeding area is identified, a qualified environmental professional should conduct an extensive search to locate the active and alternative nests and to assess the extent of suitable breeding habitat around those nests to define the actual shape and configuration of the breeding area.

- Maximize the number of nests that are included within breeding area reserves (typically all known nests).
- Establish breeding area reserves that are large enough to maintain long-term occupancy. Reserve size refers to the total amount of contiguous suitable breeding habitat within the breeding area. Reserve size is the most important factor in determining whether the breeding area will continue to be occupied by goshawks over the long term. The estimated size of breeding areas in coastal British Columbia ranges from 46 ha to 263 ha. The likelihood of continued occupancy increases with reserve size: reserves smaller than 50 ha are typically ineffective; reserves larger than 176 ha have the highest likelihood of continued occupancy.
- Maintain connectivity between all nest trees within breeding area reserves (i.e., do not isolate nest trees from each other by forest harvesting) with suitable breeding habitat, where possible, and with lower-quality forested habitat, if no other options are available to facilitate connectivity.
- Retain at least 200 m of forested habitat around all nest trees, where possible, to maintain breeding habitat and security cover near nests. Goshawks typically avoid building nests in trees that are within 200 m of a recent cutblock edge.
- Design reserves to minimize edge effects by using shapes that have low edge–area proportions and avoid long, linear shapes. Use designs that minimize the risk of windthrow and avoid reserves with sections less than 200 m wide.
- Connect breeding area reserves to adjacent forest stands to provide forested linkages to foraging habitat outside the breeding area and to provide future alternative breeding area habitat in the event the current breeding area becomes unsuitable or degraded by natural processes such as fire, forest pathogens, or windthrow.
- Avoid disturbance from industrial activities by implementing no-work zones around active nests (sufficient distance depends on the type and intensity of activity) between February 15 and September 15. If this is not practicable, avoid the most sensitive portion of the breeding season between March 15 and July 1, and (or) schedule activities nearest to the breeding area (or active nest) to occur outside this sensitive period.

Landscape Context

- Long-term breeding area occupancy and reproductive output also depend on adequate foraging habitat at the territory level. Although high uncertainty surrounds foraging habitat requirements, consistently occupied territories generally contain 40–60% suitable foraging habitat.
- Consider the range of existing breeding area reserve sizes within the same natural resource district, watershed, or timber supply area when designing new reserves and ensure known breeding areas are managed for minimal or low risk of abandonment.
- Ensure breeding area reserves are applied across the local area in a variety of suitable forest types and across biogeoclimatic variants to reduce the risk to goshawk populations from fire and pathogen outbreaks, annual fluctuations in prey types, and longer-term forest changes associated with climate change.

The impact of coastal goshawk breeding area reserves on timber supply may be reduced by overlapping reserves with one or more of the following forest harvesting constraints present under the current legislative framework, where suitable and sufficient breeding habitat exists: old growth management areas, ungulate winter ranges, wildlife habitat areas for other species at risk, land use planning objectives, parks and protected areas, wildlife tree patches, riparian reserves, inoperable forests, unstable terrain, and areas used to meet visual quality objectives.

1 Introduction

Goshawks (*Accipiter gentilis*) inhabit forested landscapes throughout circumpolar North America, Europe, and Russia (Brown & Amadon 1989; Squires & Reynolds 1997) and provide several important ecological functions. Goshawks are large territorial forest raptors that regulate prey populations (Doyle & Smith 1994; Tornberg & Colpaert 2001; Kennedy 2003) and likely influence the spacing and distribution of other forest raptors (Krüger 2002). They are a stick-nest builder whose nests are used by several other species, such as large forest owls (including Spotted Owls *Strix occidentalis*; Forsman & Giese 1997; Hobbs 2004, 2005), Common Ravens (*Corvus corax*; E.L. McClaren, pers. obs., 1998), and Great Blue Herons (*Ardea herodias*; F.I. Doyle, pers. obs., 2000). Goshawks are prized by bird-watchers and wildlife photographers because they are a rare sight. They are culturally significant to some First Nations groups; for example, goshawks in Haida Gwaii, British Columbia, were a part of the St'aawaas Xaaydagaay (Haida Cumshewa ruling family name) culture and were referred to as the "Blue Hawk," reflecting their blue-grey plumage (B. Wilson, pers. comm., 2004). As well, goshawks are sought by falconers for their aggressive nature and impressive flight and hunting skills (Squires & Reynolds 1997). Goshawks are an indicator of old and mature forest ecosystem health because they require the structural elements associated with these forests to breed and hunt (Iverson et al. 1996).

1.1 Distribution

Two **subspecies**¹ of goshawks are found in North America. The coastal subspecies (*Accipiter gentilis laingi*; hereafter referred to as **coastal goshawks**) occurs within the Pacific Northwest coast of Canada and the United States, and the interior subspecies (*A. g. atricapillus*) is more widely distributed throughout the rest of Canada and the United States (Figure 1). In the United States, coastal goshawks occur within southeast Alaska and coastal areas of Washington, and possibly Oregon and California (Jewett et al. 1953; Beebe 1974; Flatten & McClaren 2003). Within Canada, coastal goshawks occur only in British Columbia on Vancouver Island, Haida Gwaii, the islands between Vancouver Island and the coastal mainland, and along the coastal mainland of the province (Campbell et al. 1990; Cooper & Stevens 2000; McClaren 2005; Northern Goshawk *A. g. laingi* Recovery Team 2008). Using the best available information on the characteristics of forests used by coastal goshawks and their prey, the Northern Goshawk *A. g. laingi* Recovery Team mapped the range of coastal goshawks within the province to follow the wet Coastal Western Hemlock (CWH) **biogeoclimatic subzones/variants** and the Coastal Douglas-fir (CDF) **biogeoclimatic zone** (Northern Goshawk *A. g. laingi* Recovery Team 2008; Committee on the Status of Endangered Wildlife in Canada 2013). Adjacent to this range, the Recovery Team identified a **transitional zone** (Figure 1) in which **habitat** characteristics are intermediate between coastal and interior conditions (i.e., biogeoclimatic variants CWHds1, CWHds2, CWHms1, CWHms2, CWHws1, CWHws2; Green & Klinka 1994; B.C. Ministry of Forests and Range & B.C. Ministry of Environment 2010; see Appendix 2 for a key to biogeoclimatic subzone abbreviations), and in which the ranges of *A. g. laingi* and *A. g. atricapillus* may overlap (see Northern Goshawk *A. g. laingi* Recovery Team 2008).

Other sources of information that may be used to map goshawk subspecies distributions include genetic and **phenotypic** data. Both of these sources of information continue to be incomplete, especially within the province's coastal mainland forests where few goshawks have been captured for measurements and thus small sample sizes exist for genetic analysis. Recent genetic analyses suggest that goshawks in coastal areas of British

*Items in bold
are listed in
the glossary.*

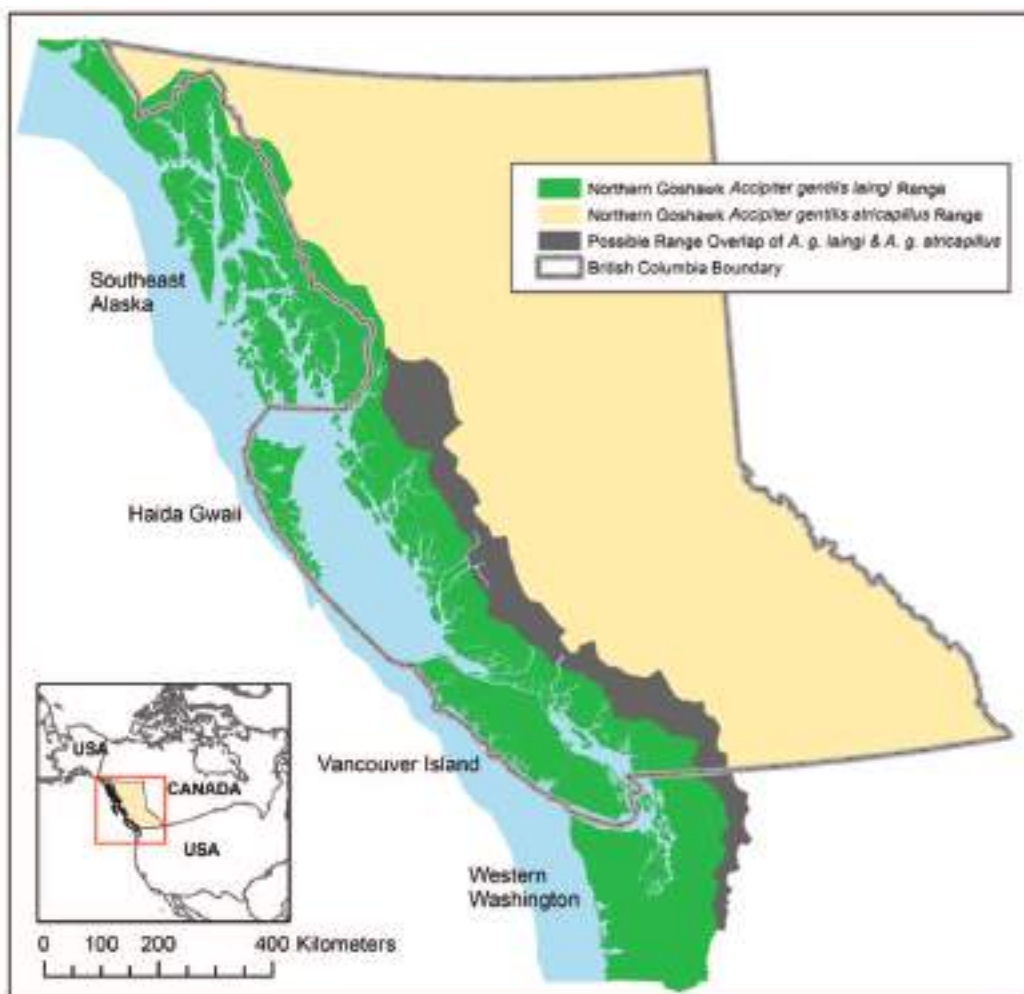


Figure 1. Range of interior and coastal subspecies of the Northern Goshawk (*Accipiter gentilis atricapillus* and *A. g. laingi*, respectively) and the potential area of subspecies overlap in British Columbia (modified from Figure 1 in Northern Goshawk *Accipiter gentilis laingi* Recovery Team [2008]).

Columbia and southeast Alaska share unique genetic characteristics which distinguish *A. g. laingi* from *A. g. atricapillus* and that populations are not **panmictic**, meaning gene flow does not currently occur among all coastal goshawk populations (Talbot et al. 2011; Sonsthagen et al. 2012). Over historical times (e.g., post- to late Pleistocene, up to several thousand generations ago), gene flow occurred among coastal goshawk populations, with some populations serving as **source populations** and some as **sink populations** (Sonsthagen et al. 2012). Although a small amount of recent gene flow has occurred from southeast Alaska and coastal mainland British Columbia to Haida Gwaii, goshawk individuals on Haida Gwaii have unique genetic signatures that are only found there. This is the locale where this subspecies was originally described (Taverner 1940; American Ornithologists' Union 1957; Beebe 1974). Individuals on Vancouver Island appear to have some genetic signatures of *A. g. laingi* and *A. g. atricapillus*, but with very few samples from adjacent coastal mainland populations, the interpretation of these genetic analyses remains unclear (Talbot et al. 2011; Sonsthagen et al. 2012).

The morphology of coastal goshawk populations inhabiting southeast Alaska, Vancouver Island, and Washington's Olympic Peninsula suggests coastal birds are smaller (as indicated by wing chord/wing length, **culmen** length, **hallux** length, and mass) than goshawk populations in other areas of western North America (interior British Columbia,

northeast Oregon, northern Arizona; Johnson 1989; Whaley & White 1994; Flatten & McClaren 2003). This subspecies' smaller size may provide improved maneuverability and subsequent prey capture within dense, coastal forests where *A. g. laingi* have a greater amount of smaller, avian prey in diets compared with *A. g. atricapillus* (Watson et al. 1998; Ethier 1999; Lewis et al. 2006; Squires & Kennedy 2006). Coastal goshawks are also described as having darker plumage characteristics (Taverner 1940; Webster 1988), possibly to increase camouflage and enhance **thermoregulation**; however, it has been difficult to quantify this phenotypic difference (Flatten & McClaren 2003). Regardless, coastal goshawks appear to use a very different prey base from interior birds, making their habits unique (Watson et al. 1998; Ethier 1999; Lewis et al. 2006).

Adult male coastal goshawk



Photo credit: Mike Stini

1.2 Ranking status

Coastal goshawks were recognized as a “**designatable unit**” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1995, when these birds were first federally listed as **Special Concern** (Duncan & Kirk 1995). As more information became available within Canada, including British Columbia, the status of the coastal subspecies was upgraded to **Threatened** because of perceived threats from habitat loss and an estimated low population of breeding adults (< 1000; COSEWIC 2000). Coastal goshawks were recently reassessed by COSEWIC and remain federally designated as Threatened (COSEWIC 2013). Reasons provided by COSEWIC for this recent status reassessment were: over half the global population resides within coastal British Columbia and continuing threats from habitat loss are predicted because of the short rotation times and extent of forest harvesting within its range (COSEWIC 2013). As well, additional threats to Haida Gwaii populations exist from a very small population size and from associated impacts to goshawk prey populations from introduced deer and their overbrowsing of understorey vegetation (Doyle 2003). This subspecies is provincially designated as **Red-listed** by the B.C. Conservation Data Centre,² whereas goshawk populations in the province's interior are considered “**apparently secure**.”

To ensure the protection of goshawks within British Columbia, both coastal and interior subspecies were designated in 1999 under the *Forest Practices Code of British Columbia Act*³ as an **Identified Wildlife Species**, and a set of forest management **guidelines** for each subspecies was developed (B.C. Ministry of Environment, Lands and Parks & B.C. Ministry of Forests 1999). Very little was known about goshawks at that time, and the management guidance provided was based on goshawk research in dry Ponderosa Pine forests in the southwestern United States (Reynolds et al. 1992). Inclusion of goshawks as an Identified Wildlife Species resulted in a heightened awareness, detection, and reporting of goshawk nests by forestry workers, as well as the initiation of several research and inventory projects on goshawks, including the two detailed in this report (see Section 3). In 2004, the Identified Wildlife Species list was re-evaluated and coastal goshawks remained classified as an Identified Wildlife Species and were also designated

as a **Category of Species at Risk** under the *Forest and Range Practices Act*.⁴ At this time, local data were used to revise provincial management guidelines (McClaren 2004). In 2004, *A. g. atricapillus* were removed from the Identified Wildlife Species list; however, several forest companies continued to manage for their breeding habitat, although no science-based guidelines were available until 2012 (Stuart-Smith et al. 2012).

Populations of *A. g. laingi* within Alaska have been petitioned several times for listing under the United States *Endangered Species Act* of 1973, but these petitions have been unsuccessful (Kennedy 1997). In 2012, however, the U.S. Fish and Wildlife Service listed *A. g. laingi* within coastal British Columbia as **Threatened** under the *Endangered Species Act*.⁵ The American rationale for listing these populations was that they constituted a *Distinct Population Segment*, meaning the British Columbia populations comprised a “significant” portion of the subspecies’ geographic range (U.S. Fish and Wildlife Service 2007). This listing does not appear to afford any immediate increase in protection to *A. g. laingi* populations in British Columbia or the United States, but it does provide a second, independent evaluation of the status of *A. g. laingi* with similar findings to those provided by COSEWIC (2013).

In Alaska, the U.S. Forest Service designated *A. g. laingi* as a **Sensitive Species** at the state level in 1994 (U.S. Department of Agriculture 1997). The Alaska Department of Fish and Game designated *A. g. laingi* as a **Species of Special Concern** in 1998 (Iverson et al. 1996; Alaska Department of Fish and Game 1998) because of threats to nesting and foraging habitats. As of 15 August 2011, the department no longer maintained a Species of Special Concern list for Alaska because the list had not been reviewed or revised since 1998.⁶ The department now manages former Species of Special Concern in its *Wildlife Action Plan* as **Featured Species**. The plan details measurable conservation goals and strategies for coastal goshawks (Alaska Department of Fish and Game 2006) and defers to the Tongass National Forest Land and Resource Management Plan for habitat protection measures, disturbance guidelines, and monitoring requirements (U.S. Department of Agriculture 2008).

In Washington, the Washington Department of Fish and Wildlife only recognizes *A. g. atricapillus* as occurring in Washington and has designated it as a “State Candidate,” a species that the Department will review for possible future listing (Desimone & Hays 2004).⁷

1.3 Regulatory framework

1.3.1 International

The Convention on International Trade in Endangered Species (CITES) lists *A. g. laingi* in Appendix II as a species that is not necessarily threatened with extinction now but may become so unless trade is closely controlled.⁸ Because of this designation, specimens exported from Canada must be accompanied by a Canadian CITES export permit.

1.3.2 Federal

The federal *Species at Risk Act (SARA)*⁹ directly protects listed individual organisms, their **residences**, and identified **critical habitat** on federally administered lands, and aquatic species and migratory birds wherever they occur. For other listed species, including *A. g. laingi* (listed under SARA Schedule 1), the primary responsibility for species’ protection falls under provincial jurisdictions.

The SARA also requires the federal minister to develop recovery strategies for all SARA-listed species within certain timelines. British Columbia fulfills its commitments to the National Accord for the Protection of Species at Risk (1996),¹⁰ and the Canada–British Columbia Agreement on Species at Risk (2005)¹¹ by preparing recovery documents

for species under provincial management authority and making these available for adoption under the *Act*. In 2008, a **recovery strategy** for the Northern Goshawk *laingi* subspecies was posted (Northern Goshawk *A. g. laingi* Recovery Team 2008) and, more recently, the provincial government posted a management plan (B.C. Ministry of Forests, Lands and Natural Resource Operations & B.C. Ministry of Environment 2013).

The *SARA* has specific content requirements for federal recovery strategies, including that critical habitat must be identified “to the extent possible” based on the “best available information.” When most provincial recovery documents are adopted under *SARA*, a federal addition is included in which critical habitat is identified. The federal “Recovery Strategy for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) in Canada,” drafted by Parks Canada (2014), adopts the 2008 provincial strategy and includes an addition that identifies critical habitat. Critical habitat identified in a final version of a recovery document posted on the *SARA* public registry must be “legally protected” (aquatic species, nests of migratory birds, and federal lands) or “effectively protected” (other species and lands). If critical habitat on provincial lands is not “effectively protected,” the federal minister must report every 6 months on steps undertaken to protect the habitat. If it remains unprotected, the federal minister must recommend to the Governor in Council that an order be created applying the *SARA* prohibitions against destruction of critical habitat to provincial lands (a Section 61 “safety net” order).

1.3.3 Provincial (British Columbia)

Legal protection for coastal goshawks in British Columbia is primarily afforded by the *Forest and Range Practices Act*, the *Land Act*,¹² the *Wildlife Act*,¹³ and the *Park Act*,¹⁴ and their associated regulations. Under the *Forest and Range Practices Act*, coastal goshawk **breeding areas** may be designated as **Wildlife Habitat Areas** with associated **general wildlife measures** (Province of British Columbia 2004) that outline allowable activities within Wildlife Habitat Areas. Under the *Land Act*, Land Use Plans can also provide legislative protection by establishing spatial reserves (e.g., Schedule 12 of the Haida Gwaii Strategic Land Use Agreement; Province of British Columbia & the Council of Haida Nation 2007) or management direction for the conservation of focal species (e.g., Central and North Coast Land Use Order, or South Central Coast Land Use Order¹⁵). The *Wildlife Act* makes the direct harm and harassment of individual goshawks illegal and protects goshawks and their eggs from possession, molestation, or destruction when birds or eggs are in nests (i.e., only when nests are active; Section 34). As well, it is illegal under the Act to harvest coastal goshawks and their eggs or young for falconry possession. The *Park Act* provides for the protection of coastal goshawks in provincial parks and protected areas by not allowing the birds to be granted, sold, removed, destroyed, damaged, disturbed, or exploited except as authorized by a valid park use permit (Section 29). Neither the *Wildlife Act* nor the *Park Act* define or explicitly protect goshawk habitat. Refer to the management plan for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) for a summary of the legal protection in place for known coastal goshawk breeding areas in the province (B.C. Ministry of Forests, Lands and Natural Resource Operations & B.C. Ministry of Environment 2013).

2 Scope and Objectives

To maintain long-term occupancy and reproductive success of coastal goshawk (*Accipiter gentilis laingi*) populations, we propose a set of science-based guidelines (i.e., **Best management practices**) for use by **qualified environmental professionals** and managers when

undertaking industrial activities, primarily forestry, around coastal goshawk **territories**. Breeding areas are the primary ecological unit for all goshawk breeding activities, including courtship, nesting, fledging, and movements of fledglings before dispersal. These areas include **nest trees** (historic, current, and potential future ones), **nest sites**, plucking posts, roosts, and **post-fledging areas** associated with each nest tree over multiple years. Coastal goshawks exhibit strong fidelity to established breeding areas and will occupy them for decades if suitable conditions persist (Bloxtton 2002; McClaren 2005; Squires & Kennedy 2006; Titus et al. 2006; Doyle 2013). These guidelines will ensure retention of effective breeding areas by using local data and applying science-based decision criteria consistently to limit **risk** to long-term occupancy by goshawks, resulting in population stability and growth. Ultimately, long-term occupancy of breeding areas and persistence of coastal goshawk populations will depend not only on the characteristics of breeding areas but on the availability of prey at larger spatial scales. Although we acknowledge the importance of larger spatial scales, we provide limited guidance for managing at these scales because less information is currently available to support strong science-based recommendations at scales larger than breeding areas.

Existing habitat guidelines for coastal goshawks are insufficient to adequately protect populations because these guidelines:

- are outdated (i.e., Identified Wildlife Management Strategy; McClaren 2004);
- are not designed for application throughout the entire provincial range of coastal goshawks (U.S. Department of Agriculture 2008; Coast Forest Conservation Initiative 2012);
- are focused on urban development activities rather than on forestry activities (Province of British Columbia 2013);
- are not strictly science based, as trade-offs are made between habitat recommendations and impacts on timber supply or economics (McClaren 2004; Coast Forest Conservation Initiative 2012; TimberWest & Island Timberlands 2012; Wilson 2012); and
- are not based on local data analyses to adapt recommendations to coastal forest ecosystems.

2.1 Science-based management

The best management practices presented here were developed by a team of professional biologists using the **science-based management** approach outlined by Mills et al. (2001). Although the phrase “science-based management” is widely used in resource management discussions, few formal criteria define this management approach. We focused on the following two criteria outlined in Mills et al. (2001):

- Maximizing the use of local data to guide management; and
- Presenting a range of management options (and their predicted relationships to long-term occupancy of breeding areas by goshawks) from which qualified environmental professionals can choose on the basis of competing values and different risk tolerances.

In the process of developing these best management practices, we followed several specific principles and approaches, such as:

- Establishing *a priori* methods for conducting analyses and interpreting results;
- Providing clear documentation of the rationale, assumptions, methods, and results associated with our analyses and management recommendations to facilitate critical review and different interpretations;

- Providing clear documentation of uncertainties and information gaps;
- Using a precautionary approach when full scientific certainty was not achievable (Government of Canada 2003);
- Providing a comprehensive and balanced data and literature review that enables readers to see alternative perspectives and make their own conclusions about the validity of our interpretations and recommendations in the context of other studies;
- Linking management recommendations to data-driven, habitat-use and habitat-fitness relationships, to the extent possible;
- Describing habitat attributes and configurations that are important to coastal goshawks and enabling flexible management solutions to meet these conditions, rather than providing specific prescriptions;
- Involving several species experts and other resource management professionals with a diversity of skill sets, experience, and perspectives in the development of these guidelines;
- Incorporating a formal peer review of these guidelines and the methods used to create them before releasing the report; and
- Improving and refining management recommendations through time as knowledge improves.

Under the *Forest and Range Practices Act*, the provincial government sets objectives for the forested land base that the forest industry and licensees must meet through the development of results and strategies. This model of governance is based on the accountability of qualified environmental professionals and the attendant codes of practice and ethics of their governing bodies. To define and manage coastal goshawk habitat, **Registered Professional Biologists** and **Registered Professional Foresters** rely on their respective organizations' codes of ethics and the guidance provided by their jointly published "Managing Species at Risk in British Columbia" (College of Applied Biology & Association of B.C. Forest Professionals 2009). Such a results-based approach provides qualified environmental professionals with the opportunity to use creative, site-specific strategies to meet management objectives, which often includes balancing multiple resource values, without the constraint of prescriptive guidelines that define how to achieve these objectives. The science-based guidelines presented here support a results-based approach by providing resource professionals with specific information about the probable consequences of management actions along a risk-tolerance gradient and the ecological responses used to assess success. For example, when goshawk habitat designation and protection is ineffective, consequences could include breeding area abandonment or relocation of breeding areas to future resource extraction areas, which could result in increased costs, increased uncertainty, resource extraction delays, or legal consequences.

These guidelines are tailored specifically for coastal goshawks inhabiting ecosystems within their provincial range. A similar document, using consistent methods, was prepared for interior goshawks (Stuart-Smith et al. 2012). When qualified environmental professionals and managers are operating in areas of potential range overlap between the two subspecies (see Figure 1), the habitat characteristics and potential prey composition of the area are used to determine whether interior or coastal guidelines apply (e.g., Snowshoe Hares [*Lepus americanus*] and ground squirrels [*Spermophilus* sp.] are more representative of drier habitats associated with the interior goshawks). In cases where uncertainty exists, qualified environmental professionals and managers are advised to apply the coastal goshawk guidelines, as per the precautionary principle.

3 Long-term Studies on Coastal Goshawks

The best management practices presented in this report rely heavily on data obtained from two independent, long-term inventory, monitoring, and research projects that took place in coastal British Columbia—one on Vancouver Island and adjacent coastal islands (1994–2012) and the other in Haida Gwaii (1995–ongoing). Because these studies were fundamental in developing the management guidelines, we provide a brief description of the study areas, objectives, and reports related to each project.

3.1 Vancouver Island

This study area is dominated by the Coastal Western Hemlock (CWH) biogeoclimatic zone, which is the most productive temperate forest region in Canada (Pojar et al. 1991). The dominant tree species at lower elevations are western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*), although amabilis fir (*Abies amabilis*) and red alder (*Alnus rubra*) are also abundant. Above 900 m, the species composition changes to mountain hemlock (*Tsuga mertensiana*), yellow-cedar (*Chamaecyparis nootkatensis*), and subalpine fir (*Abies lasiocarpa* var. *lasiocarpa*). Vancouver Island has rugged mountains dissected by many creek drainages.

Mean daily temperatures range from 4.4°C in winter (October–April) to 14.5°C in summer (May–September). Mean monthly precipitation ranges from 167.9 mm in winter to 60.3 mm in summer. Most precipitation falls as rain.¹⁶

Forest harvesting was initiated in the study area in the late 1800s and steadily increased between 1910 and the 1980s, when harvest levels peaked (U.S. Fish and Wildlife Service 2007; B.C. Ministry of Forests, Mines and Lands 2010). Nearly one-half of the productive forest on Vancouver Island has been harvested over the last 100 years, with well over one-third of the forested land base now consisting of second- and third-rotation forests between 0 and 100 years in age (U.S. Fish and Wildlife Service 2007; B.C. Ministry of Forests, Mines and Lands 2010). Most accessible low-elevation forests are in their second or third rotations, whereas old-growth forests remain primarily in reserves, remote valley bottoms, parks and protected areas, or at higher elevations. The main harvest regime on Vancouver Island is clearcutting, with variable levels of single tree and patch retention (B.C. Ministry of Forests, Mines and Lands 2010). Currently, windthrow and forest pathogens are the dominant natural disturbance regime throughout the study area, creating relatively small canopy gaps of 10 trees or fewer (Dorner & Wong 2003).

Table 1. Number of known and predicted coastal goshawk territories within the four conservation regions in coastal British Columbia.

Coastal goshawk conservation region	Known territories ^a	Model predicted territories ^b	
		Current Conditions	Capable conditions
Vancouver Island	102	261	459
South Coast	25	201	296
North Coast	21	228	361
Haida Gwaii	17	40	65

^a Unique breeding areas with at least 1 year confirmed occupancy by breeding goshawks.

^b Unpublished modelling output from Smith (2012); average of five model runs using a 40% suitable foraging habitat threshold.

Data were collected from inventory and monitoring activities that occurred throughout Vancouver Island and adjacent coastal islands from 1994 to 2012, and from research that occurred from 1994 to 2002. During this time, 102 goshawk territories were located, which represents approximately 39% of the territories estimated to be supported within current landscapes on Vancouver Island, under a moderate suitable foraging habitat threshold (Table 1; Smith 2012; B.C. Ministry of Forests, Lands and Natural Resource Operations & B.C. Ministry of Environment 2013; Mahon et al. 2015). Within the Vancouver Island study area, coastal goshawk work involved the following primary objectives:

- Quantify local nesting habitat characteristics by conducting standardized **broadcast surveys** within three landscape types: (1) contiguous second-growth forests (40–140 years old); (2) contiguous old-growth forests (> 250 years old); and (3) fragmented (largely cut, unconnected patches of old-growth and second-growth) forests on Crown forest lands (Ethier 1999; McClaren 2005; Manning et al. 2012). Broadcast surveys were also conducted on private forest lands (Toews & Wall 2012), but study area design differed as well as survey methodology.
- Test the effectiveness of various inventory techniques, including broadcast surveys (Dickson 2001; McClaren et al. 2003); **dawn vocalization surveys** (Zee-man 2003); and **stand-watch surveys** (Bartzen 2000) in coastal forest environments.
- Determine nest tree and breeding area fidelity patterns through annual occupancy assessments of known nest trees and breeding areas, using broadcast surveys and radio-telemetry (McClaren et al. 2005; Manning et al. 2012; Toews & Wall 2012).
- Determine the breeding season diet of coastal goshawks through pellet collection and analysis and observations at nest blinds (Ethier 1999; McClaren 2005).
- Assess the relationship between harvest patterns around breeding areas and both annual occupancy (McClaren & Pendergast 2003; McClaren 2005) and nest productivity (McClaren et al. 2002) patterns. These data were collected through assessing annual occupancy of known nest trees and breeding areas (broadcast surveys and radio-telemetry) and monitoring active nests to estimate the number of young fledged (McClaren 2005; Manning et al. 2012; Toews & Wall 2012).
- Assess the relationship between Red Squirrel (*Tamiasciurus hudsonicus*) abundance (point counts) and goshawk annual occupancy patterns (broadcast surveys and radio-telemetry; Pelletier 2000).
- Assess the size and habitat characteristics of post-fledging areas used by young goshawks before they leave breeding areas (McClaren et al. 2005).
- Estimate the breeding season and **annual home range** size and habitat use patterns (using radio- and satellite-telemetry) of coastal goshawks (McClaren 2005).
- Determine dates for breeding phases including courtship, incubation, nestling, fledgling, post-fledging period, and initiation of dispersal (McClaren 2005; McClaren et al. 2005).
- Determine the genetic and phenotypic characteristics of coastal goshawk populations (Flatten & McClaren 2003; Talbot et al. 2011; Sonsthagen et al. 2012).
- Collect anecdotal information on potential disturbance factors to coastal goshawks during the breeding season and other basic behavioural traits from blind observations near active nests (Ethier 1999; McLaughlin 2002; E.L. McClaren, unpublished data).

3.2 Haida Gwaii

Haida Gwaii is an isolated island archipelago off the west coast of British Columbia that covers approximately 90 000 km². The climate of Haida Gwaii is very mild. The annual temperature averages 8°C, with precipitation occurring approximately two-thirds of the year. Rainfall varies greatly depending on location, with up to 450 cm/year on the exposed windward west coast and up to 80 cm/year on the sheltered leeward side of the islands.¹⁷ Its temperate rainforest lies within the CWH wet hypermaritime biogeoclimatic subzone, with the landscape primarily dominated by western hemlock, Sitka spruce (*Picea sitchensis*), and western redcedar at lower elevations, and mountain hemlock and yellow-cedar at higher elevations (Green & Klinka 1994). Over the past century, 74% of the Skidegate Plateau has been harvested (Gowgaia Institute 2007); this ecosystem contains the most productive forest stands in Haida Gwaii and covers approximately one-third of Graham and Moresby islands (Demarchi 2011). The primary method of harvest in Haida Gwaii is clearcutting (B.C. Ministry of Forests, Mines and Lands 2010). Windthrow and forest pathogens are the dominant natural disturbance regime throughout this study area, creating relatively small canopy gaps of 10 trees or fewer in older forests (Dorner & Wong 2003).

Through a combination of its isolation (~80 km from the mainland) and its past glacial history, during which it served as a glacial refugium (Warner et al. 1982), Haida Gwaii has a unique assemblage of species, with fewer terrestrial species compared to similar coastal mainland rainforests in the province (e.g., one grouse species, no native squirrels). Furthermore, many of the native species are genetically unique and (or) have distinctive phenotypes and, as such, have been described as distinct subspecies (Burg et al. 2005, 2006; Topp & Winker 2008). Over the past 100 years or so, many non-native species have been introduced to Haida Gwaii, including red squirrels and black-tailed deer (*Odocoileus hemionus sitkensis*), which are affecting the abundance and distribution of the unique endemic island species (Gaston et al. 2008).

Coastal goshawk inventory, monitoring, and research was initiated on Haida Gwaii in 1995 (Chytyk & Dhanwant 1999) and, to date, 17 territories containing 40 nest trees have been located (Doyle 2013). This number of known territories represents approximately 42% of territories estimated to be supported within current landscapes in Haida Gwaii, under a moderate suitable foraging habitat threshold (Table 1; Smith 2012; B.C. Ministry of Forests, Lands and Natural Resource Operations & B.C. Ministry of Environment 2013; Mahon et al. 2015). Within the Haida Gwaii study area, coastal goshawk work involved the following primary objectives:

- Quantify local nesting habitat requirements, using stratified broadcast and stand-watch surveys across all seral stages (Chytyk & Dhanwant 1999; Doyle 2012).
- Determine the size of the breeding population through annual inventory within new areas and from monitoring known territories using broadcast surveys (Doyle 2012).
- Conduct research on focal prey populations to determine their status and threats (**introduced species** and seral stage conversion) and to develop potential mitigation strategies (Doyle 2005b; Doyle et al. 2012).
- Determine prey selection and foraging habitat characteristics (Roberts 1997; Doyle 2005a; Doyle 2006a).
- Develop landscape forest harvest and silviculture practices that minimize impacts on foraging habitat and breeding area suitability (Doyle 2004a; Doyle 2004b; Doyle 2005b; Doyle 2006c).

- Determine the genetic isolation of the population through feather and egg-shell collections (Talbot et al. 2011; Sonsthagen 2012).
- Determine the potential impacts of annual weather patterns and forecasted climate change scenarios on coastal goshawk habitat availability and occupancy patterns (Doyle 2005b; Doyle 2009; Doyle 2012; Doyle et al. 2012).

3.3 Summary of other coastal goshawk study locations

3.3.1 Mainland coastal British Columbia

A 2-year inventory and monitoring project occurred within the Bella Coola valley area of the North Island–Central Coast Natural Resources District between 2007 and 2008 (Mitchell et al. 2008). During this time, seven coastal goshawk territories were located.

As well, *ad hoc* nest reporting, inventory, and monitoring work occurred between 1996 and 2012 within the Sunshine Coast, Squamish, and Chilliwack Natural Resource Districts. Overall, approximately 46 territories are currently known within the coastal mainland portion of *A. g. laingi*'s range. This number of known territories represents approximately 11% of territories estimated to be supported within current landscapes on the mainland coast of British Columbia, under a moderate suitable foraging habitat threshold (Table 1; Smith 2012; Mahon et al. 2015; B.C. Ministry of Forests, Lands and Natural Resource Operations & B.C. Ministry of Environment 2013). These study areas were not included in our breeding area size or territory-spacing analyses because either the survey methods were non-standardized, breeding area monitoring occurred for less than 3 years, and (or) surveys were not conducted using equal effort across broad landscapes, which is required to estimate breeding density. To help develop the coastal goshawk best management practices, we included data on breeding area habitat characteristics and prey types used by breeding goshawks within these studies because the findings of Daw et al. (1998) and Titus et al. (2006) suggested that habitat characteristics of goshawk nests are not biased by location method (i.e., forestry activities vs. stratified random surveys).

3.3.2 United States

Other long-term coastal goshawk inventory, monitoring, and research studies have occurred in two key coastal areas of the United States—southeast Alaska and the Olympic Peninsula portion of western Washington. In southeast Alaska, just over 70 territories were located between 1991 and 2005 in a study area spanning 500 km² (Iverson et al. 1996; Titus & Lewis 2000; Flatten et al. 2001; Lewis et al. 2006; Titus et al. 2006). Within the Olympic Peninsula, approximately 52 territories were located primarily between 1990 and 2010, but some were located as early as 1970–1989 (Watson et al. 1998; Bloxton 2002; Finn et al. 2002a). We did not include raw data from these studies in any of the analyses we conducted, as we were unsure whether the survey methods were comparable to the Vancouver Island and Haida Gwaii study areas; however, to help develop the coastal goshawk best management practices, we extensively reference these studies and compare their results to ours.

3.4 Analyses of coastal goshawk data to support these guidelines

When developing this report, several data summaries and analyses were conducted to provide management recommendations and to ensure current, local data were used where possible. The majority of these analyses were updates of data presented in previous documents (McClaren 2005; Northern Goshawk *Accipiter gentilis laingi* Recovery Team 2008; Horn et al. 2009b; Daust et al. 2010; Doyle 2012; Smith 2012, 2013; Mahon et al. 2015).

The information in these documents was updated to: (1) incorporate new nest locations that were found over the last 5 years; (2) refine the methodology; or (3) expand the analysis to a larger data set or geographic area. Analyses and data summaries presented here used a September 2012 database of coastal goshawk nest sites compiled by B.C. Ministry of Forests, Lands and Natural Resources Operations, which contains 360 goshawk nest trees within 167 breeding areas. Initial data screening removed seven nests that were either outside the coastal goshawk range or that had obvious location errors, resulting in a reduced total of 353 nest trees from 163 breeding areas. The methods and results of six specific analyses are integrated into the following sections of this document:

- numbers of nests and spacing patterns among alternative nests within breeding areas (Section 4);
- distances between neighbouring breeding areas (territory spacing; Section 4);
- habitat characteristics associated with nest trees (Section 5.1);
- analysis of the distance of goshawk nests from recent cutblock edges compared to random points (Section 5.1);
- estimation of goshawk breeding area sizes (Section 5.3); and
- amounts of modelled suitable and capable foraging habitat surrounding known breeding areas on Vancouver Island and Haida Gwaii (Daust et al. 2010; J. Smith and R. Vennesland, unpublished data, Section 5.4).

Appendix 3 also contains information on the detailed methodology used to update analyses.

4 Breeding Ecology of Coastal Goshawks

The coastal goshawk is a raven-sized raptor primarily adapted to forested habitats where its short rounded wings, long tail, and powerful flying action make it an effective direct pursuit hunter, capable of quick acceleration and excellent maneuverability through vegetation. Goshawks are **socially monogamous**, territorial, **non-colonial**, **synchronously breeding** raptors (Kennedy 2003; Kenward 2006). Coastal goshawks are characterized as non-migratory (Iverson et al. 1996; Bloxton 2002; McClaren 2005), although in some years adults may move from **breeding home ranges** to **non-breeding home ranges**. Furthermore, males and females have unique home ranges with varying degrees of overlap (Iverson et al. 1996; McClaren 2005). Consequently, habitat management strategies implemented around goshawk breeding areas need to consider sufficient habitat for both males and females during the breeding season.

4.1 Individual age

Most individuals initiate breeding at over 2 years of age, but some females breed at 1–2 years old (Squires & Reynolds 1997; Kenward 2006). On Vancouver Island, six second-year females were observed breeding over 9 years of inventory and monitoring (McClaren 2005). After birds are older than 3 years, age cannot be reliably determined from plumage characteristics (Bond & Stabler 1941).

4.2 Breeding chronology

During the winter and into the courtship period, females must reach a critical body mass required for egg laying (Marcström & Kenward 1981; Newton et al. 1983). Therefore, prey availability in late winter and early spring influences the onset of breeding each year (Keane 1999). Females obtain nearly all food from mates during the pre-laying, incubation, and

early nestling periods (Duncan & Kirk 1995; Iverson et al. 1996). Females lay eggs in mid-to late April and incubation (primarily by the female) occurs for 30–32 days (Beebe 1974; Iverson et al. 1996; McClaren 2005; McClaren et al. 2005). Hatching occurs between mid-May and early June, with young fledging 38–42 days later in early to mid-July (McClaren et al. 2005). Fledglings are fed by their parents for 35–55 days (McClaren et al. 2005) within nursery areas near nests called post-fledging (family) areas (Reynolds et al. 1992). The total time from when adult females lay eggs until young initiate dispersal is 100–127 days (Titus et al. 1994; Kennedy & Ward 2003; McClaren et al. 2005; Wiens et al. 2006).

4.3 Productivity, occupancy, and survival

Female goshawks lay only one clutch of 1–4 eggs per breeding season (Iverson et al. 1996; Squires & Reynolds 1997; McClaren 2005; McClaren et al. 2005; Doyle 2012). The average number of young fledged from **active nests** was:

- 1.6 ± 0.1^{18} between 1994 and 2002 for Vancouver Island ($n = 141$; McClaren 2005);
- 1.6 ± 0.2 between 1995 and 2012 for Haida Gwaii ($n = 49$; Chytky & Dhanwant 1997; Doyle 2012); and
- 2.1 between 1991 and 1998 in southeast Alaska ($n = 87$; Titus et al. 1999).

Goshawks do not breed every year and annual **occupancy rates** of breeding areas for *A. g. laingi* are variable (Vancouver Island: 55%, $n = 163$, McClaren 2005; Haida Gwaii: 30%, $n = 122$, F. I. Doyle, unpublished data; western Washington: 40%, $n = 50$, Finn et al. 2002b; southeast Alaska: 45%, $n = 283$, Flatten et al. 2001). Generally, individual breeding areas are occupied by breeding pairs once every 2–3 years. Several long-term studies in coastal forests have documented nest stands to be re-occupied by coastal goshawks (albeit individuals may differ from year to year) over 12–18 years, the entire length of time these studies were operating (Bloxtton 2002; McClaren 2005; Titus et al. 2006; Doyle 2013). In longer-term European studies, goshawks have re-occupied the same nest stands for several decades (Kenward 2006). These data suggest that breeding areas will continue to be used as long as sufficient suitable foraging habitat exists near suitable breeding areas. Although some breeding areas may go for several years without being occupied (Titus et al. 2006; Manning et al. 2012; Doyle 2013), they are still important to regional populations. Within coastal goshawk breeding areas on Vancouver Island and in Haida Gwaii, up to 6 years have passed between occupancy events over 17 years of continuous monitoring (F.I. Doyle, unpublished data; E.L. McClaren, unpublished data).

Lifetime reproductive success for coastal goshawks is unknown, but low juvenile survival (estimates for this subspecies are unavailable) and high **turnover rates** of adult females (78.9% annually; $n = 57$) within breeding areas on Vancouver Island suggest it could be low (McClaren 2005). A long-term study on European goshawks reported adult females to breed for a median of 2 years of their lifespan and produce a median of two nestlings over this time (Krüger 2005). Likewise, in Arizona, females and males spent an average of 2.2 ± 0.1 years and 1.9 ± 0.1 years, respectively, as breeders (Wiens & Reynolds 2005). Little information exists on survival rates for coastal goshawks; adult *A. g. gentilis*

Nearly fledged coastal goshawk chicks (ca. 40 days old)



Photo credit: Ross Vennesland

can live up to 18 years (Kenward et al. 1999). In southeast Alaska, Iverson et al. (1996) analyzed radio-telemetry data using mark-recapture analyses to estimate mean annual survivorship of adults (genders combined) to be 0.7 ($n = 39$; 95% CI: 0.6–0.9) and 0.6 ± 0.1 ($n = 31$) for adult males only (K. Titus, unpublished data).

4.4 Habitat characteristics

Northern Goshawks build large stick nests below the canopy, and within the lower third or half of the tree height. A sample of 14 nests on Vancouver Island averaged 92.7 ± 4.3 cm across and 7.9 ± 0.7 cm interior cup depth (E.L. McClaren, unpublished data). Typically, goshawk nests are in one of the largest diameter trees in the nest stand (Iverson et al. 1996; Ethier 1999; Titus et al. 2006), but sometimes nests will be in smaller trees with deformities (such as proliferous branching caused by hemlock dwarf mistletoe [*Arceuthobium tsugense*]), multiple leaders, or other structures that provide suitable platforms for these large nests.

Examples of suitable coastal goshawk breeding areas in various stand types: (A) old-growth Western Hemlock dominant; (B) 60–80 year co-dominant Western Hemlock and Douglas-fir; (C) old-growth Douglas-fir dominant; (D) old-growth Western Red-cedar dominant (Haida Gwaii).



Photo credit: Eric McClaren (A, B, C); Nick Reynolds (D).

In general, goshawks select breeding habitat based on stand structure rather than on stand age and species composition. Stand structure that provides breeding habitat for coastal goshawks usually includes a closed canopy, open understorey, subcanopy flyways, and suitable nest platforms (Iverson et al. 1996; Ethier 1999; Titus & Lewis 2000; Finn et al. 2002b; McClaren 2005; Mahon et al. 2015). These characteristics are commonly best developed in mature and old structural stages (B.C. Ministry of Forests and Range & B.C. Ministry of Environment 2010). However, suitable breeding habitat characteristics may begin to occur in younger stands (45–60 years) that have high site productivity and have succeeded through natural stand thinning or have received silvicultural treatments, such as pruning or thinning, at an early age (McClaren 2005; Tripp & Coombs 2009; Toews & Wall 2012; Mahon et al. 2015).

4.5 Nest tree and breeding area spacing patterns

In Haida Gwaii and on Vancouver Island, 92% of **alternative nests** were within 1 km of each other, with an average inter-nest tree spacing distance of 375 ± 17 m ($n = 415$ nest pairs). In southeast Alaska, 79% of alternative nests were within 1 km of each other and 100% were within 3.2 km of each other (Titus et al. 2006). Even when a nest falls out of a tree, it may be rebuilt if the tree continues to provide a suitable nest platform. Occasionally, multiple nests were built in the same tree (McClaren 2005).

During the breeding season, goshawks aggressively defend the breeding area, including aerial displays by the males to ward off other males and to attract mates. This territorial behaviour results in goshawk pairs spacing themselves relatively evenly throughout landscapes where **suitable breeding** and **foraging habitat** are fairly contiguous (Reynolds & Joy 1998; Reich et al. 2004; McClaren 2005; Rutz et al. 2006), with the distance between pairs being driven by regional-level prey availability (Doyle & Smith 1994, 2001; Reich et al. 2004; Doyle 2006b). The spacing between breeding areas in coastal forests varies regionally from approximately 6.9 ± 0.2 km ($n = 101$) across Vancouver Island to 10.4 ± 0.5 km ($n = 14$) on Haida Gwaii. Breeding area densities vary sub-regionally, likely because of forest productivity and prey availability, with spacing distances possibly as close as 4–5 km in some areas on Vancouver Island (J. Deal, unpublished data; D. Lindsay, unpublished data) and on the mainland coast (Mitchell et al. 2008).

Sooty grouse are a common prey of coastal goshawks.



Photo credit: Berry Wijdeven

4.6 Foraging

Goshawks are **central-place foragers** in the breeding season; the birds return to the nest to feed their young and (or) mate, which constrains how far they can travel from the nest to forage. In theory, central-place foragers adjust their territory shape and size to maximize the amount of food acquired relative to time and energetic expenditures and competition from neighbours (Schoener 1971; Pyke et al. 1977). Populations of coastal goshawks inhabit islands and dense coastal forests with a low

abundance and diversity of prey compared to the drier interior forests occupied by *A. g. atricapillus* (Roberts 1997; Ethier 1999; Bloxton 2002; Doyle 2005b; Lewis et al. 2006). Mammalian prey items comprise less of coastal goshawk diet than that of *A. g. atricapillus* (Watson et al. 1998; Ethier 1999; Bloxton 2002; Andersen et al. 2003; Lewis et al. 2006). In forests of southeast Alaska, British Columbia, and western Washington, coastal goshawks feed on various mid-sized prey, ranging from small mammals and tree squirrels to passerines (primarily thrushes and jays), woodpeckers, and grouse (Titus et al. 1994; Roberts 1997; Watson et al. 1998; Ethier 1999; Bloxton 2002; Doyle 2005b; Lewis et al. 2006). Unlike *Buteo* hawks (e.g., Red-tailed Hawks, *Buteo jamaicensis*), which soar in open habitats while hunting, goshawks generally hunt within forests or along forest edges where they use a stop-and-go, short-stay, perched-hunting pattern (Kenward 1982; Kennedy 2003), maneuvering between trees below the forest canopy.

5 Coastal Goshawk Territory Components

Goshawks exhibit strong territoriality (Squires & Kennedy 2006). This behaviour affects population density, distribution, movement patterns, and habitat use, all of which have implications for forest management. We use the term “territory” to refer to the total area used by a pair of resident goshawks on an annual basis. A goshawk territory contains several hierarchically arranged components. The original goshawk **territory model** was proposed by Reynolds et al. (1992), and since then various terms have been used by different goshawk researchers to refer to territory components and concepts, resulting in the unclear use of terminology (Andersen et al. 2005). We attempt to clarify that here.

Table 2. An overview of key components of goshawk territories and their approximate scale/extent from key studies in North America.

Territory component	Description	Approximate scale/extent	References
Nest tree	Tree containing a goshawk stick nest. Most territories contain multiple nest trees (sometimes termed “alternative” nest trees) that are relatively close to each other and that are used in different years.	Tree	Clough 1994; Reynolds et al. 1994; Woodbridge & Detrich 1994; Speiser & Bosakowski 1988; Ethier 1999; Finn 2000; McGrath et al. 2003
Nest site	Forest patch surrounding a nest tree that is thought to capture unique habitat characteristics associated with the nest tree (i.e., nest access, cover, microclimate).	< 1 ha	Titus et al. 1994; Ethier 1999; Finn 2000; McGrath et al. 2003; Desimone & DeStefano 2005
Nest area	Contiguous area of suitable goshawk breeding habitat surrounding the cluster of nest trees. This area also typically includes a buffer from nest trees to hard edges (i.e., well-defined edges where forest abuts non-forest or recently disturbed stands) to reflect goshawk avoidance of nesting immediately adjacent to hard edges.	< 50 ha	Hall 1984; Reynolds et al. 1992; Clough 1994; Woodbridge & Detrich 1994; Iverson et al. 1996; Ethier 1999; Finn 2000; Flatten et al. 2001; Squires & Kennedy 2006

Table 2. (continued)

Territory component	Description	Approximate scale/extent	References
Satellite nest	Single nest tree > 1000 m from the main cluster of nest trees that typically defines the nest area and breeding area.	Tree	Woodbridge & Detrich 1994; Reynolds & Joy 1998
Post-fledging area	Area used by fledgling goshawks, within a given year, from fledging until dispersal. This area typically surrounds the active nest tree but not always.	15–230 ha in coastal B.C.	Iverson et al. 1996; McClaren et al. 2005; Titus et al. 2006
Breeding area	This is the primary ecological unit for all goshawk breeding activities, including courtship, nesting, fledging, and movements of fledglings before dispersal. This area includes nest trees (current and potential future ones), plucking posts, roosts, and post-fledging areas associated with each nest tree over multiple years.	46–263 ha in coastal B.C. 170 ha in N. Idaho	Defined in Section 5 Moser & Garton (2009)
Breeding home range	Area used by a pair of goshawks during the breeding season, encompassing both the breeding area and foraging areas. The breeding home range is smaller than the non-breeding home range because of central-place foraging constraints related to supporting young at nests and a greater degree of territoriality during this time of year. Less overlap occurs between adjacent breeding home ranges than for adjacent annual home ranges.	3700 ha (VI) – 8500 ha (HG) in coastal B.C. 643–10 730 ha other studies	Iverson et al. 1996; Finn et al. 2002a, 2002b; Bloxton 2002; Squires & Kennedy 2006
Non-breeding home range	Area used by individual goshawks to obtain food during the fall and winter seasons. This home range often includes portions of the pair's breeding home range.	~11 900 ha in S.E. Alaska ~3500–8400 ha in Interior B.C.	Kenward 1982; Stephens 2001; Tornberg & Colpaert 2001; Titus et al. 2006; Mahon 2008
Annual home range	Area that includes the annual movements of a resident, breeding pair of goshawks with an established territory during all seasons. Adjacent pairs' annual home ranges may have varying degrees of overlap.	15 719–47 563 ha in S.E. Alaska 3500–8400 ha in Interior B.C.	Lewis & Flatten 2004 Mahon 2008

The territory hierarchy presented here and in Stuart-Smith et al. (2012) is a modified version of the original Reynolds et al. (1992) model and, in our opinion, clarifies the biological relevance and scale of key territory components (Table 2; Figure 2). The nest tree is the smallest scale. The area of forest immediately surrounding the nest tree (< 1 ha) is the nest site. Most territories contain multiple nest trees close to one another, and the area encompassing the cluster of nest trees is the **nest area**. Rarely, a **satellite nest** occurs well outside the nest area (> 1000 m from other nests). Surrounding each nest tree is a post-fledging area, which is used by juvenile goshawks after they fledge but before they disperse. The location of this area can be different each year, depending on the location of the active nest tree, the vegetation types and topography surrounding it, direction of food deliveries from adults, and variation in the number and behaviour of fledglings (McClaren et al. 2005; Harrower et al. 2010). We define the breeding area as the combined space of multiple post-fledging areas around each nest tree in the same territory (see expanded discussion below). Beyond the breeding area are three home ranges (breeding, non-breeding, and annual home ranges), defined relative to the breeding season, that goshawks use for foraging. The portion of home ranges where goshawks pursue and capture prey is referred to as the **foraging area**. In coastal British Columbia, territorial defence of breeding areas and other portions of territories, results in a regular spacing of territories across landscapes with suitable habitat. Spacing between breeding areas varied from an average of 6.9 km between breeding areas on Vancouver Island to an average of 10.4 km on Haida Gwaii (see Section 4). These differences likely reflect the amount and quality of suitable forest in which to hunt, the abundance of prey, and availability of suitable breeding areas.

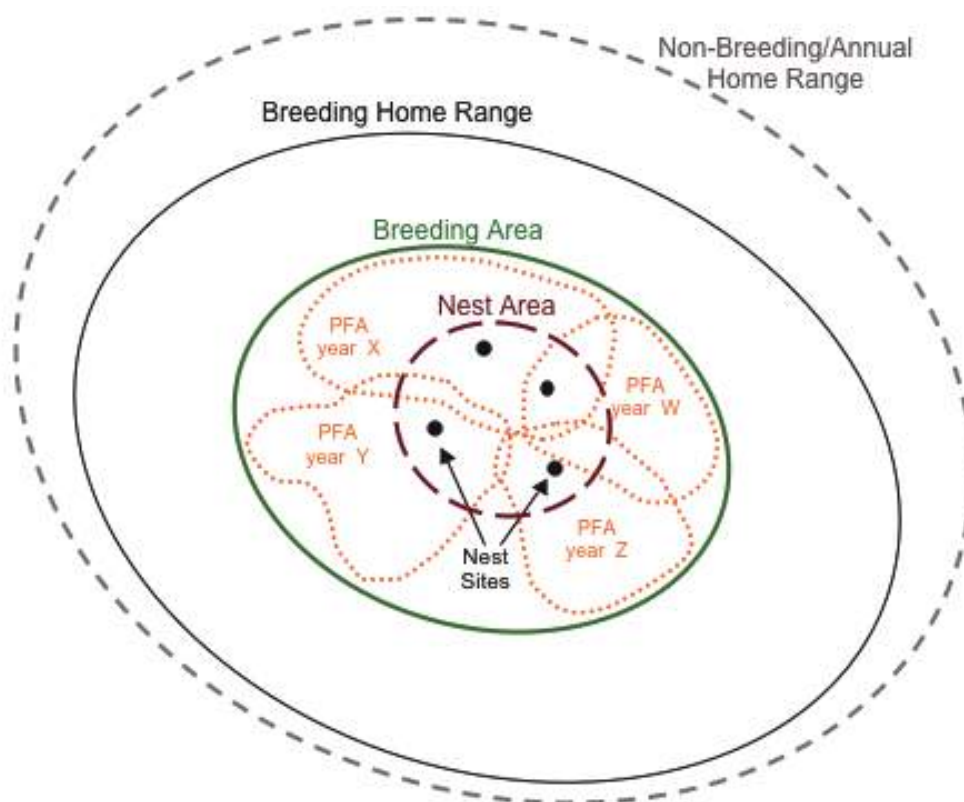


Figure 2. Conceptual diagram of coastal goshawk territory components, including the nests, nest area, post-fledgling areas (PFA), breeding area (not to scale), breeding home range, and non-breeding/annual home range. For diagrammatic ease, most territory components are portrayed by an ellipse; in reality, these components may assume a more irregular shape (modified from an original conceptual model presented in Reynolds et al. [1992]).

The breeding area is our key scale of focus for the proposed best management practices. The breeding area concept we use here is very similar in ecological context to the post-fledging family area described by Reynolds et al. (1992)—an expanded area beyond the nest area that is used by both fledglings and adults during the fledgling-dependency period over multiple years. We use the term “breeding area” to avoid ambiguity in the way the term “post-fledging area” has been used to describe related, but different, concepts. For example, post-fledging area is sometimes used to describe:

- the defended area of a goshawk’s territory (e.g., Reynolds et al. 1992);
- the combined area used by juveniles and adult female goshawks during the fledgling-dependency period over many years (e.g., Kennedy et al. 1994; Squires & Kennedy 2006); and
- the area used by fledgling goshawks during the fledgling-dependency period in 1 year (e.g., McClaren et al. 2005; Harrower et al. 2010).

Our terminology alleviates the potential confusion between these concepts by referring to the fledgling use area before dispersal as the “post-fledging area” and the larger area of combined post-fledging areas surrounding each nest tree as the “breeding area.” Our definition is consistent with that provided by Moser and Garton (2009).

Breeding areas are the key functional unit for all aspects of goshawk breeding ecology, including courtship, incubation, and post-fledging activities, as well as roosting and food deliveries; as such, it is likely the area regularly defended by adults. Commensurately, management actions will be inadequate if aimed at maintaining long-term breeding of known goshawk nests at scales smaller than the breeding area (e.g., habitat buffers around individual nest trees). Long-term occupancy of breeding areas and goshawk population persistence will depend not only on the characteristics of breeding areas, but also on the availability of prey and foraging habitat at larger spatial scales. The availability and abundance of prey in relation to existing breeding areas, along with the characteristics of the breeding area itself, determine the quality of the breeding area. Quality of the breeding area can be determined by its long-term (> 10 year) occupancy rate or, perhaps more importantly, by its long-term contribution to the next generation of goshawks. A primary management goal is to maintain the intact nature and quality of existing breeding areas because of the strong role of goshawk territorial interactions in determining the location of breeding areas. Displaced goshawk pairs cannot simply relocate if alternative breeding areas are not available within their territory.

Key Definition

The Breeding Area is the primary ecological unit for all goshawk breeding activities, including courtship, nesting, fledging, and movements of fledglings before dispersal. This area includes post-fledging areas associated with each known and potential future nest tree over multiple years.

An important aspect of goshawk territoriality relating to forest management is that goshawks have strong fidelity to breeding areas. Once established, goshawks may use a given breeding area for periods of years or decades, including continued use after failed breeding attempts and occupation by new birds if the original occupants disappear (Squires & Reynolds 1997; Harrower 2007; McClaren 2005; Mahon 2008; Harrower et al. 2010). Although satellite nests are occasionally built outside the typical breeding area boundaries (Woodbridge & Detrich 1994; Reynolds & Joy 1998), for management purposes, the breeding area is usually consid-

ered as a spatially fixed resource or residence. Once a given breeding area is located and adequately protected, there is a strong likelihood that goshawks will use that area for multiple years, unless significant natural disturbance affects the breeding area (i.e., windthrow, landslides, avalanches), or the suitability of the breeding home range changes dramatically.

Key Points

- Goshawks are territorial and distribute their territories regularly across the landscape where suitable habitat exists; average regional spacing distances range from 6.9 to 10.4 km in coastal British Columbia, although sub-regional spacing distances may be closer.
- A goshawk territory contains several hierarchical components, each with specific patterns of behaviour and seasonal use.
- The breeding area is the ecologically functional unit for all goshawk breeding activities and is the focus and smallest scale for management activities.
- A breeding area may be used by a pair of goshawks for years or even decades, if conditions remain suitable.

5.1 Nest site and nest area characteristics

Despite significant variation in forest types used for nesting across their geographic range, goshawks consistently use certain structural attributes of forests for nesting. These attributes include trees with branch sizes and forms capable of supporting large stick nests, and relatively closed-canopy stands with corresponding open subcanopy flyways (Penteriani 2002; Kenward 2006; Squires & Kennedy 2006). These attributes are often associated with mature or old forest structures but may occur in stands of various ages, depending on stand composition, site history, stand treatments, site productivity, and stand height (see reviews by Penteriani [2002], Kenward [2006], and Squires & Kennedy [2006] for descriptions of the range of forest characteristics observed in other studies).

To document the range of environmental conditions around goshawk nest trees (i.e., nest-stand scale) within coastal British Columbia, B.C. Ministry of Forests, Lands and Natural Resource Operations staff conducted a GIS query for us that intersected nest locations with biogeoclimatic subzone maps and four forest stand variables from Vegetation Resource Information maps. The latter map data were only available for about two-thirds of all nest locations. A summary of stand variables associated with this screened subset of nests is provided in Table 3 and Figure 3. Goshawk nests occur primarily (99%; Mahon et al. 2015) within the CWH biogeoclimatic zone (Banner et al. 1993; Green & Klinka 1994). Nest trees are well distributed across most CWH subzones, with the exception of the hypermaritime (vh) subzone, which is dominated by low productivity bog forests and appears to have significantly lower nesting habitat potential for goshawks than other CWH subzones. Although no nest trees are known in the Coastal Douglas-fir (CDF) zone, it is expected to offer equally suitable structure to the CWH zone, although only relatively small patch sizes (< 50 ha) remain and many are near human development (Negrave & Stewart 2010). Only one nest occurred in the Mountain Hemlock (MH) zone (and that

site was transitional to CWH), suggesting that coastal goshawks may avoid nesting in this zone. Two nests from one breeding area in the transition zone between coastal and interior goshawk ranges occurred in the Interior Douglas-fir (IDF) zone. The higher-elevation MH and Engelmann Spruce–Subalpine fir (ESSF) zones generally offer reduced suitability for nesting owing to poorer tree forms, smaller trees, and open canopies.

The tree species occurring in coastal British Columbia offer varying suitability for goshawk nest platforms (Mahon et al. 2015). Western hemlock, Douglas-fir, and Sitka spruce have forms that tend to result in good subcanopy flyways and branch platforms, and these were the dominant species associated with both nest trees and breeding areas. Yellow-cedar, western redcedar, and subalpine fir offer poor branching structures for nest platforms and their stands often have poor subcanopy flyways. Despite the suboptimal form of western redcedar for nest trees, it formed a minor (10–40%) component of several coastal nest stands. Amabilis fir and mountain hemlock tend to offer moderate quality branching platforms and subcanopy flyways. In regenerating forests or along overgrown roads, red alder may offer short-term suitability as nest trees.

Coastal goshawk nests in various tree species and ages: (A) old-growth Douglas fir; (B) 60–80 year Douglas-fir; (C) old-growth Sitka Spruce; (D) old-growth Western Red-cedar; and (E) 60–80 year Red Alder.



Photo credits: Erica McClaren (A, D, E); Frank Doyle (C); Ross Vennesland (B).

The structural maturity of a stand, and tree species composition within a stand, form the fundamental basis of nesting suitability for goshawks. Using the provincial structural stage (SS) classification (B.C. Ministry of Forests and Range & B.C. Ministry of Environment 2010), most breeding areas were Mature (SS 6) and Old Forest (SS 7), but Young Forest (SS 5) that had proceeded through the self-thinning stage and had developed subcanopy flyways and suitable branch platforms (i.e., large enough to support a nest) were also sometimes used ($n = 163$; Table 3). Because structural stage was not available from most forest cover databases, we also summarized nesting habitat suitability relative to stand age and height. Nesting suitability varied with stand age and height, depending on site productivity and tree species, but by far the majority ($> 80\%$) of nests occurred in stands ≥ 30 m tall and ≥ 90 years old ($n = 163$; Table 3; Figure 3). Most ($> 90\%$) breeding areas were associated with slopes $< 60\%$ and relatively closed-canopy stands (50–80%), which often correspond to good subcanopy flyway development (Table 3; Figure 3). The purpose of this summary is to provide general attributes associated with suitable nesting habitat across coastal British Columbia. For a more detailed description of these attributes, refer to the Northern Goshawk *Accipiter gentilis laingi* Recovery Team habitat models (Mahon et al. 2015).

Goshawks often nest in one of the largest diameter trees in the forest stand (Squires & Kennedy 2006). Although goshawks may build a new nest each year, they also re-use nests built in previous years. Sometimes they build multiple nests in one tree (F. Doyle & E. McLaren, pers. comm.). Within coastal breeding areas, the number of known nests ranged from 1 to 12, whereas the median number of nest trees depended on search effort. With one or more thorough nest searches conducted to locate alternative nest trees and at least 3 years of breeding area monitoring, the median number of alternative nest trees within breeding areas was three (see Appendix 4). The average distance between nest trees

Table 3. Summary of coastal goshawk stand characteristics and nest trees ($n = 353$ nest trees; $n = 163$ breeding areas from Vegetation Resource Inventory and Digital Elevation Model data) in coastal British Columbia.

Biogeoclimatic zone (subzone) ^a	<i>Suitable</i> : CDF (all), CWH (all except vh) <i>Reduced Suitability</i> : CWH (vh), MH (all), ESSF (all)
Forest composition	<i>Suitable</i> : western hemlock, Douglas-fir, Sitka spruce, <i>Reduced Suitability</i> : amabilis fir, red alder, cottonwood <i>Unsuitable</i> : yellow-cedar, lodgepole pine, western redcedar, subalpine fir
Structural stage ^b	Most nests were in Mature (SS 6) and Old Forest (SS 7); occasionally in Young Forest (SS 5) that had proceeded through self-thinning stage and had developed sub-canopy flyways and suitable branch platforms (i.e., large enough to support a nest)
Stand height	Most ($> 80\%$) nests were in stands at ≥ 30 m; some stands suitable at 24 m
Stand age	Most ($> 80\%$) nests were in stands ≥ 90 years; some stands suitable at 65 years
Canopy closure	98% of known nests were in stands with 50–75% canopy closure
Slope	Majority (92%) of nests on slopes 0–60%; reduced suitability 60–100%; generally unsuitable $> 100\%$.

^a Appendix 2 contains a key to biogeoclimatic zone and subzone abbreviations.

^b Following standard provincial structural stage codes (B.C. Ministry of Forests and Range & B.C. Ministry of Environment 2010).

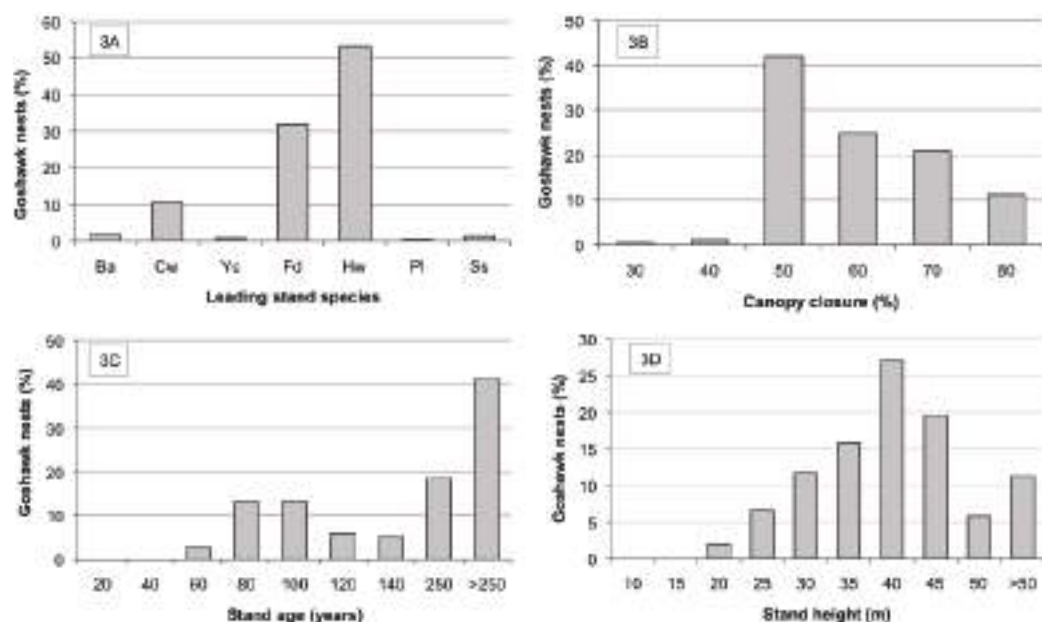


Figure 3. Stand characteristics associated with coastal goshawk nest sites in British Columbia: (A) leading stand species (see Appendix 2 key to tree species codes); (B) percent canopy closure; (C) stand age; and (D) stand height ($n = \sim 280$ nests; data not available for all nests).

within the same breeding area was 375 ± 17 m, with a range of 0–1667 m ($n = 415$ nest pairs). The majority (80%) of nests were within 500 m of each other and fewer than 10% of nests were more than 1000 m apart (Figure 4). The nests that were 800–1667 m apart mainly fell into three categories:

- nests were on Haida Gwaii ($n = 7$ nest pairs);
- areas contained a geographic feature, such as a lake or large gully, that nests were spaced around ($n = 16$); or
- new nests were established away from recent clearcut edges near original nests ($n = 23$, Figure 5).

Nest trees in the same breeding area were typically in a contiguous forest stand. Nest trees were occasionally separated by narrow forest openings, such as secondary roads, seismic lines, wetlands, and small streams, but rarely by larger openings, such as cutblocks, railways, highways, or transmission lines. Mahon et al. (2008) observed very low and low rates of nest location within 100 m and 200 m of cutblock edges, respectively, for 148 nests on Vancouver Island. To verify this pattern, we used our updated nest tree database for Vancouver Island and Haida Gwaii ($n = 283$) to recalculate the distance of goshawk nest trees from cutblock

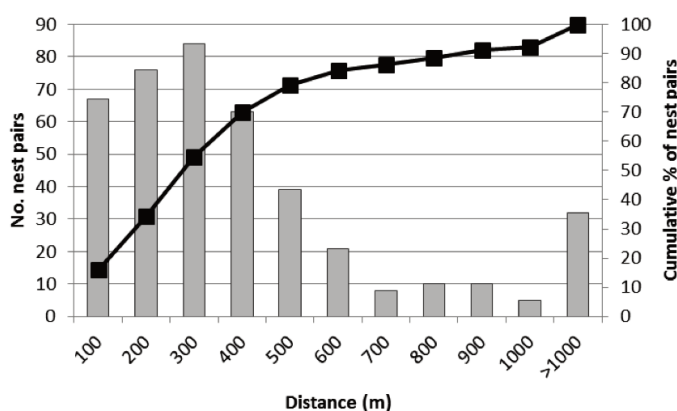


Figure 4. Frequency distribution of distances between coastal goshawk nests within the same breeding area in British Columbia ($n = 415$ pairwise comparisons from 353 nests and 163 breeding areas).



Figure 5. The farthest distances between coastal goshawk nests within the same breeding area were often in cases where recent harvest blocks occurred near goshawk nests and new nests were built farther away from these cutblocks.

edges and compared this to the distances of 5000 random points from cutblock edges on Vancouver Island. We did not use the full set of 353 nest trees because cutblock data were unavailable for some areas. To calculate the distances of nests to recent cutblock edges, we used the cutblock layer from the time the nest was first discovered, as this was the closest estimate we had of cutblock occurrence relative to when goshawks selected nest trees. Of the 283 nests analyzed, only one occurred less than 100 m from a cutblock edge and 96% were greater than 200 m from cutblock edges (Figure 6). By comparison, 40% of the random points ($n = 5000$) were less than 200 m from cutblock edges. This difference may indicate avoidance of areas within 200 m of cutblock edges by coastal goshawks when building new nests; however, some exceptions to this pattern were noted where goshawks continued to use nests after cutblock edges were created within 200 m of them (J. Deal, unpublished data; D. Lindsay, unpublished data). The degree to which forest edges deter goshawks from locating new nests likely depends on many ecological factors, including the regional suite of predators and competitors that may frequent edge environments. Within coastal forests, the bulk of ecological edge effects (e.g., changes in microclimate, increased windthrow, increased predation) have been documented to occur within 50–100 m of stand edges (Bunnell et al. 1999; Canadian Marbled Murrelet Recovery Team 2003; Malt & Lank 2009). Thus, coastal goshawks may avoid these edge effects by placing most nests away from recent cutblock edges, whereas when cutblocks are placed near existing nests, goshawks sometimes continue to use them because of high site fidelity.

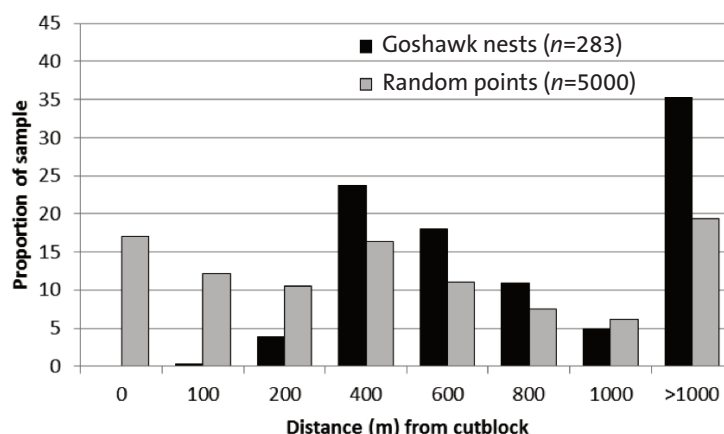


Figure 6. A comparison of the distance from cutblocks of 283 coastal goshawk nest trees relative to random points on Vancouver Island and Haida Gwaii, B.C.

Key Points

- Key conditions associated with suitable goshawk breeding habitat in coastal British Columbia are:
 - trees with large lateral branches or deformities that are able to support large stick nests;
 - stand structure that provides an open understorey and subcanopy flyways;
 - stands with 50–80% canopy cover; and
 - slopes of less than 60%.
- Forest stands that provide these characteristics are often structurally mature or old, are dominated by western hemlock or Douglas-fir, and contain trees ≥ 30 m high and ≥ 90 years old.
- Multiple nest trees typically occur within breeding areas, and most alternative nest trees are within 1000 m of each other.
- Coastal goshawks avoid nesting within 0–200 m of recent cutblock edges.

5.2 Post-fledging area characteristics and fledgling movements

The post-fledging area is the annual activity area used by fledgling goshawks for 35–55 days (4–8 weeks) after they fledge and before they disperse from active nests (Kennedy et al. 1994; McClaren et al. 2005; Harrower 2007). These areas surround active nest trees and may correspond to the **core-use areas** of adult females (Kennedy et al. 1994). The size and location of post-fledging areas varies from year to year, depending on the location of active nests, the number of fledglings and their movement patterns, the distribution of habitat within the breeding area, and the behaviour of adult birds (i.e., adult female core-use area [Kennedy et al. 2004]; prominent direction of food deliveries [Harrower et al. 2010]). The cumulative area covered by unique and potentially overlapping post-fledging areas around alternative nest trees within a territory during many active breeding years defines the size and extent of the overall breeding area (Figure 7). Because each alternative nest tree within a territory has a post-fledging area associated with it, the number of nest trees and spacing pattern among them also influences breeding area size.

For species such as goshawks that have long parental-care periods, post-fledging areas appear to serve a crucial role in the survival of fledglings through the post-fledging period (McClaren et al. 2005). When adults are away foraging, these areas provide security cover from predators when young are vulnerable and learning to fly. These areas also provide opportunities for young to learn and practice hunting skills, while still serving as a central place for food deliveries. As a result, this component of goshawk territories has been recognized as important for goshawk habitat management and has been directly incorporated into several management guideline documents (Reynolds et al. 1992; B.C. Ministry of Water, Land and Air Protection 2004; Stuart-Smith et al. 2012). Using a 95% adaptive ker-



Figure 7. Size estimates for two coastal goshawk breeding areas using an overlay of three estimates of post-fledging area size (50%, 70%, 90% percentiles) around all known nests in the breeding area. Coloured dots represent fledgling locations in different years.

nel estimate, McClaren et al. (2005) estimated coastal goshawk post-fledging area sizes of 15–230 ha (mean: 59.2 ± 16.1 ha) from 12 radio-tagged fledglings over 2 years of data collection (Table 4). Although the average sample size of locations per fledgling on Vancouver Island was relatively small ($n = 18$), estimates are not correlated to sample size ($r^2 = 0.02$, $n = 12$). This estimate is larger than a similar study that used a fixed kernel estimator to calculate post-fledging area sizes of 10–71 ha (mean: 36.7 ± 6.6 ha) from 15 radio-tagged *A. g. atricapillus* fledglings within the Interior of British Columbia (Harrower et al. 2010). If a bias was associated with the relatively small sample sizes in these studies, it would likely be toward underestimating post-fledging area size, as larger numbers of locations typically result in larger home range size estimates (Kerohan et al. 2001).

Table 4. Estimates of coastal goshawk post-fledging area (PFA) size using 95% adaptive kernel utilization distributions from radio-telemetry data on Vancouver Island, British Columbia (McClaren et al. 2005).

Study area	No. PFAs	Mean no. locations per PFA	Size (ha)			
			Mean	90th Percentile	70th Percentile	50th Percentile
Vancouver Island	12	17.8	59.2	75.4	51.8	45.5

Coastal goshawk fledglings on Vancouver Island spent an average of 45.9 ± 1.3 days within post-fledging areas (McClaren et al. 2005). This post-fledging period was similar to *A. g. atricapillus* fledglings in Arizona, which spent an average of 46.3 ± 0.8 days ($n = 71$; Wiens et al. 2006b), although longer than *A. g. atricapillus* fledglings at interior British Columbia locations, which averaged 37 days in the post-fledging area (Harrower et al. 2010). The length of time that fledglings remain in post-fledging areas depends on

several factors, including environmental effects (prey abundance, weather), territory effects (hatching date, brood size), and individual effects (gender, body mass; McClaren et al. 2005; Wiens et al. 2006b). As goshawk fledglings mature, they become more mobile and move farther from active nests (> 800 m); however, occasional forays back to active nest trees throughout the post-fledging period suggest nest trees are an important reference feature during this time (McClaren et al. 2005). Fledgling locations are usually not equally distributed in a circular fashion around active nests, and the size and shape of post-fledging areas vary among fledglings. Harrower et al. (2010) reported that *A. g. atricapillus* fledgling locations were offset in one direction from active nests and suggested that this direction may correspond to the direction from which adult females arrived with prey deliveries. Post-fledging areas are composed almost entirely of forest greater than 40 years old (and generally of forest greater than 80 years old) and are structurally mature and old (Harrower et al. 2010).

On Vancouver Island, habitat associations with post-fledging area locations have not been analyzed, and therefore specific habitat recommendations for these areas, which are generally different from breeding habitat, cannot currently be made. Interestingly, in approximately half of the breeding areas monitored, fledglings moved from nest trees into denser, younger seral-stage forests that were downslope but connected to their nest stands (E.L. McClaren, unpublished data). During the early post-fledging period, fledglings are poor fliers and may spend a lot of time on the ground or in the lower canopy (McClaren et al. 2005). It is possible that dense forests provide increased protection from predators during this vulnerable time. The consistent pattern of movement downslope from active nests probably results from the weak flying ability of fledglings. As well, fledglings remained within or at the edges of forested stands and were not observed within adjacent forest openings (i.e., clearcuts).

Vancouver Island post-fledging area habitat characteristics seem more variable than other locations. In southeast Alaska, where a 1500 m radius was drawn around known nest trees ($n = 136$) to describe a hypothetical post-fledging area, 40% of areas (on average) were within productive old-growth forests (Titus et al. 2006). Other studies that examined habitat use and selection by fledglings have found that fledglings avoid young seral forests and non-forested habitats and select mature forests with dense canopies and small openings (see review in Squires & Kennedy 2006; Harrower et al. 2010; Stuart-Smith et al. 2012).

Key Points

- The post-fledging area is the annual activity area used by fledgling goshawks for 4–8 weeks after they fledge and before they disperse from their natal territory.
- On Vancouver Island, coastal goshawk post-fledging area sizes averaged 59.2 ± 16.1 ha ($n = 12$, range = 15–230 ha).
- Fledglings were observed to remain within forested breeding areas rather than in adjacent open habitats.

5.3 Estimating the size of breeding areas in coastal British Columbia

Because these best management practices focus on the breeding area as the key management unit for conserving goshawk nesting opportunities, we made a substantial effort to

quantify breeding area sizes using data from coastal British Columbia. Using the following criteria, we estimated the size of 63 of the 167 known breeding areas that

- had a thorough (see Appendix 4 for what constitutes “thorough”) nest search conducted to locate alternative nest trees;
- were monitored for at least 3 years; and
- were occupied by breeding goshawks at least 1 year after the territory was initially located.

Table 5. Estimated size (ha) of 63 coastal goshawk breeding areas in British Columbia, using three post-fledging area sizes to buffer nest trees (see Section 5.3, Table 4, and Figure 7). Variation in estimates of breeding area size results from variation in the number of nest trees and spacing of nest trees within breeding areas.

Breeding area size estimates	Post-fledging area size (ha) $n = 12$		
	90th percentile	70th percentile	50th percentile
Maximum	263.4	198.1	178.2
90th percentile	175.2	128.3	16.6
70th percentile	146.5	103.5	92.7
50th percentile	114.7	84.3	76.2
Minimum	75.4	51.8	45.6

For each territory ($n = 63$), we assessed breeding area sizes by first buffering each nest tree within the same territory with a circular post-fledging area size as estimated from Vancouver Island data (Table 4), and then we calculated the combined area of these buffers within each territory. Internal overlapping boundaries between these buffers were dissolved and the outermost shared boundary was used to calculate the breeding area size (Figure 7). To represent the variation in post-fledging area sizes, we calculated each breeding area using the buffers based on the 90th, 70th, and 50th percentiles of the 12 post-fledging area sizes reported for Vancouver Island by McClaren et al. (2005; Table 4, Figure 7); this generated three sets of nest buffers. To summarize the range of plausible breeding area sizes generated for each set of buffers, Table 5 presents the results (using the 90th, 70th, and 50th percentiles in Table 4) along with maximum and minimum breeding area size estimates. Breeding area size estimates ranged from 46 to 263 ha; variation in size within each percentile resulted from differences in the number of nest trees and the inter-nest spacing patterns unique to each territory (Table 5).

Key Points

- The breeding area represents the fundamental ecological unit used by goshawks for nesting and rearing activities within a territory, over multiple years.
- Breeding area size was estimated using the combination of multiple nest trees and multiple post-fledging areas surrounding these nest trees, within a territory.
- Breeding area size estimates ranged from 46 to 263 ha, with 50th and 90th percentiles of 76 and 175 ha, respectively.

5.4 Home range and foraging habitat

The primary activity of goshawks outside the breeding area is foraging. The suitability of foraging habitat for goshawks is affected by a combination of prey abundance and structural attributes that enable access to prey (i.e., prey availability is a function of prey abundance and accessibility). Their ambush style of hunting, frequent use of vegetated areas that obscure detection, and sensitivity to observer disturbance make it difficult to measure the foraging activities and hunting success of goshawks. Because it is difficult to measure prey availability and hunting success, foraging habitat selection is often inferred by the amount of time adults spend in different habitat types, and then by assuming the most utilized habitat types represent the most important hunting areas (Tapia et al. 2007). Although habitats used by goshawks for foraging are generally similar to those used for nesting (i.e., structurally mature and old forests), foraging occurs in a wider range of habitats that may lack nest sites but still offer adequate prey and suitable vegetation for hunting. Foraging areas may include shrub and pole/sapling stage stands, riparian habitats, high-elevation forests, and sparsely treed habitats such as alpine and wetlands (Iverson et al. 1996; Squires & Reynolds 1997; Good 1998; Squires & Kennedy 2006). Goshawks preferentially use forests in which prey are more accessible over forests in which prey is more abundant but less accessible (Beier & Drennan 1997; Good 1998; Drennan & Beier 2003; Beier et al. 2008). In a summary of goshawk radio-telemetry studies ($n = 12$) in North America, Greenwald et al. (2005) concluded that goshawks show selection for mature and old forests compared to non-forested or young forests, and nine of the 12 studies showed goshawk selection for stands with higher canopy closures and larger trees when compared to unused, randomly selected stands. These attributes offer goshawks subcanopy flyways, provide perches for ambush hunting, and provide good visibility of, and limited escape cover for, prey (Squires & Kennedy 2006). Reynolds et al. (2008) suggested that the range of foraging habitats used by goshawks is broader than the conclusions drawn by Greenwald et al. (2005) and that a mixture of habitat types near breeding areas which support prey diversity is beneficial to goshawks. In conclusion, several studies suggest goshawks preferentially select structurally mature and old forests with good access to primary prey over young forests or non-forested habitats with high prey abundance; however, some debate exists about how widely this selection applies across ecosystems with different prey species and structural attributes.

In coastal forests, radio-telemetry data suggest goshawks select foraging habitats that are primarily mature and old structured forests characterized by closed canopies, relatively large diameter trees, and open understories (Iverson et al. 1996; Bloxton 2002; McClaren 2005; Titus et al. 2006; U.S. Fish and Wildlife Service 2007). Within these forests, coarse woody debris and snags provide important habitat elements for prey, as well as hunting perches and plucking posts for goshawks. Primary prey associated with mature and old coastal forests include red squirrels, forest grouse, and passerines (thrushes, wood-

Coastal goshawk plucking post with multiple avian prey remains.



Photo credit: Erica McClaren

peckers, jays; Ethier 1999; Bloxton 2002; Doyle 2005b; Lewis et al. 2006; Titus et al. 2006). In addition to the primary prey found in mature and old forests, other habitats and prey are used, albeit to a lesser degree. In the late summer and fall, coastal goshawks have been observed to hunt migratory birds along subalpine and alpine ridge tops (E. McClaren, pers. obs.; D. Doyle, pers. obs.). In winter months, they are known to hunt grouse and ptarmigan within subalpine forests, and overwintering ducks and shorebirds along coastlines, coastal estuaries, and farmlands interspersed with treed patches (Iverson et al. 1996; Bloxton 2002; McClaren 2005; Titus et al. 2006). Preferred foraging habitats also appear to vary both regionally (McClaren 2005; Doyle 2006b; Lewis et al. 2006; Titus et al. 2006) and temporally (McClaren 2005; Titus et al. 2006), and between male and female goshawks (U.S. Fish and Wildlife Service 2007). Long-term occupancy and successful breeding of goshawks will be improved if foraging areas with abundant prey are maintained in juxtaposition with breeding areas.

Although relatively abundant information exists on the habitat types used by goshawks for foraging and by their prey, little information is available that quantifies the amount and spatial arrangement of foraging habitat required within a goshawk territory to support a breeding pair. Minimum requirements, or thresholds, likely vary regionally and temporally in response to fluctuations in prey availability, habitat quality, brood size, and by individual (hunting efficiency, experience; Kennedy et al. 1994). For example, Bloxton (2002) observed that foraging areas of coastal goshawks in western Washington doubled in size following a strong La Niña event, and that it declines in the relative abundance of prey. Additionally, Bloxton (2002) reported that goshawks concentrated foraging activities within 5 km of active nests and within only 15% of their entire breeding home range. In general, it is more difficult to discern unique patterns of habitat selection by goshawks at larger scales and as the landscape context around nests becomes more varied (Iverson et al. 1996; Ethier 1999; Daw & DeStefano 2001; Finn et al. 2002a; McClaren & Pendergast 2003; McGrath et al. 2003). Methods and scales for measuring amounts of foraging habitat within territories also vary among studies, making comparisons difficult. Three studies demonstrated a positive relationship between the amount of mature forest within territories and territory occupancy patterns (Ward et al. 1992; Patla 1997; Finn et al. 2002a). Minimum threshold requirements were generally not evident in these studies, although Finn et al. (2002a), working in Washington's Olympic Peninsula, reported that territories with occupied nests had 40% or more of late-seral forest with high canopy closure, less stand initiation cover, and reduced landscape heterogeneity at the 177 ha and 1886 ha scales than at similar scales around unoccupied nests.

For coastal British Columbia, Smith and Vennesland (unpublished data; see Appendix 3 for a detailed methodology) used the **Northern Goshawk A. g. laingi Recovery Team foraging habitat suitability and territory analysis models** (Smith & Sutherland 2008; Mahon et al. 2015) to estimate the proportion of suitable foraging habitat (habitat suitability index > 0.5) that occurred in modelled territories surrounding known goshawk nests on Vancouver Island and Haida Gwaii. Within estimated territories for Vancouver Island ($n = 82$) and Haida Gwaii ($n = 18$), fewer than 7% of territories on Vancouver Island and none on Haida Gwaii had less than 20% modelled suitable foraging habitat (J. Smith & R. Vennesland, unpublished data; Figure 8). On Vancouver Island, most territories (83%) contained 30–70% of modelled suitable foraging habitat. This pattern remained similar (85%) when only territories that were consistently occupied (see Appendix 3; $n = 39$) were included in the analysis, although fewer territories in this subset had less than 20% suitable foraging habitat (3% vs. 12%; Figure 8). On Haida Gwaii, most territories (84%) contained

40–70% of modelled suitable foraging habitat (Figure 8). These results are comparable to a similar analysis by Daust et al. (2010) that used circular territory estimates around known nests, rather than modelled territories, to summarize the amount of suitable foraging habitat within consistently occupied territories. When the amount of modelled suitable foraging habitat around known nests was compared to the amount of modelled suitable foraging habitat within randomly generated territories (assumed to be unoccupied by coastal goshawks), the proportions of suitable foraging habitats did not substantially differ (E.L. McClaren, unpublished data; J. Smith & R. Vennesland, unpublished data). Interpretations of these analyses are somewhat limited because we report on observed amounts of suitable foraging habitat within known coastal goshawk territories that are consistently occupied, rather than being able to clearly link the amount of suitable foraging habitat in home ranges to measures of goshawk fitness (but see more about landscape type and breeding occupancy relationships in Section 6.2). More data are required to determine how much foraging habitat is required by coastal goshawks to maintain viable territories, with this amount likely varying on a sub-regional and annual basis.

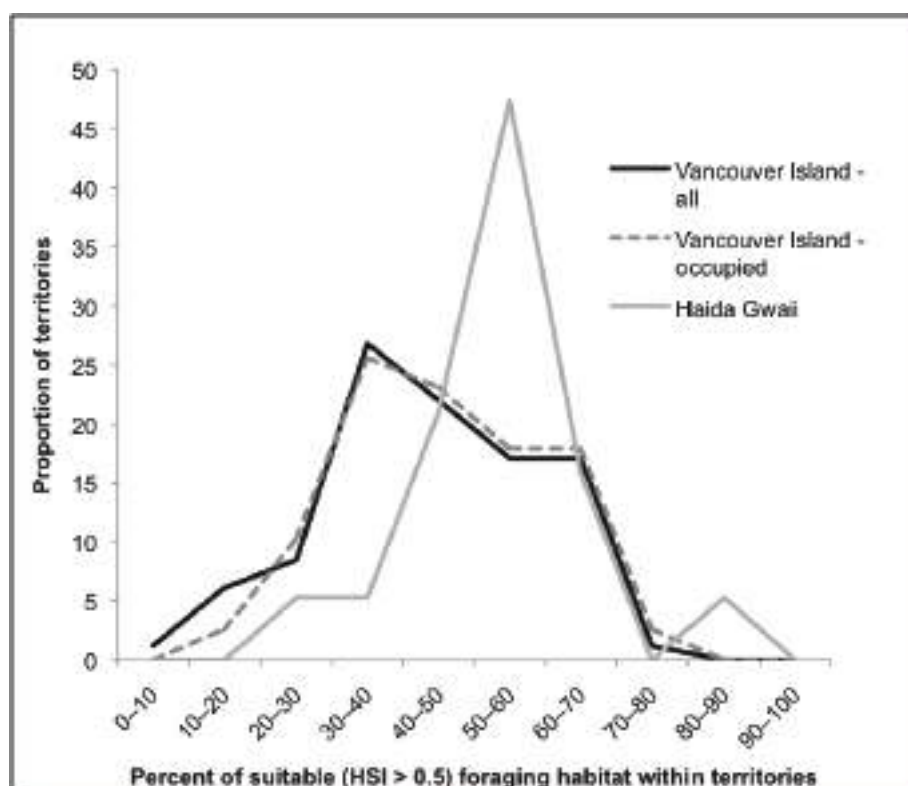


Figure 8. Distribution of coastal goshawk territories relative to percent of modelled suitable (habitat suitability index > 0.5) foraging habitat within territories. Vancouver Island study area data are shown for all territories and for only those that continue to be occupied within the past 5 years of monitoring.

Based on habitat modelling, the overall amount of suitable foraging habitat within landscapes that support coastal goshawks has diminished over the past 250 years (Smith & Sutherland 2008; J. Smith & R. Vennesland, unpublished data; Figure 9). For example, using the *A. g. laingi* Recovery Team foraging habitat and territory models (Smith & Sutherland 2008; Mahon et al. 2015) to estimate the amount of capable foraging habitat available historically within modelled goshawk territories on Vancouver Island and Haida Gwaii¹⁹ showed that at least half of all territories in both study areas had more than 70% capable foraging habitat, whereas approximately half of all territories in these study areas

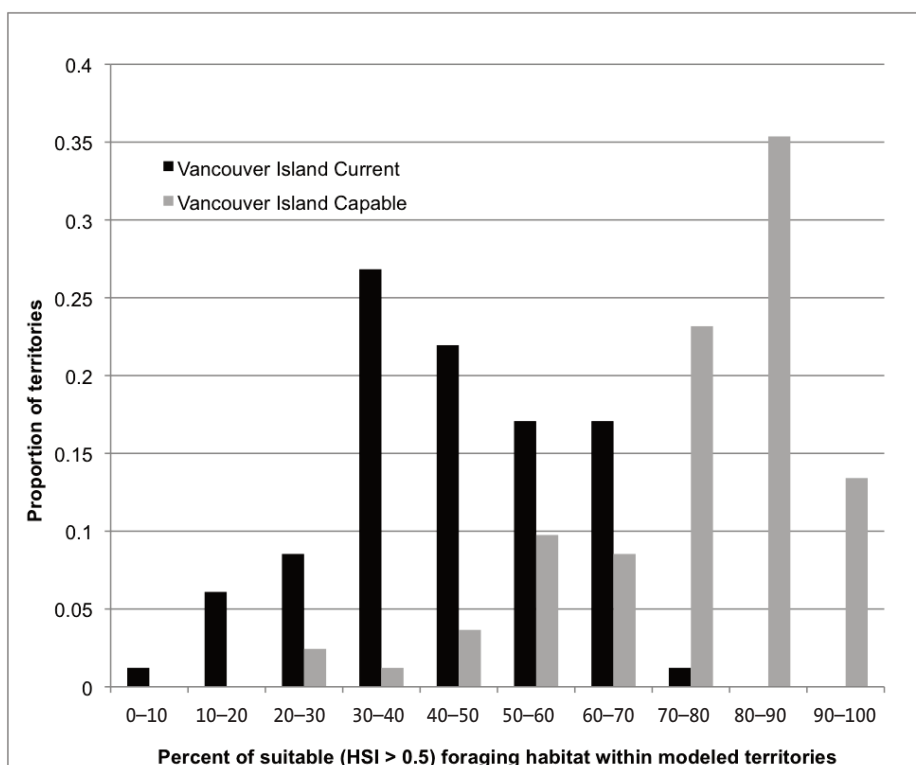
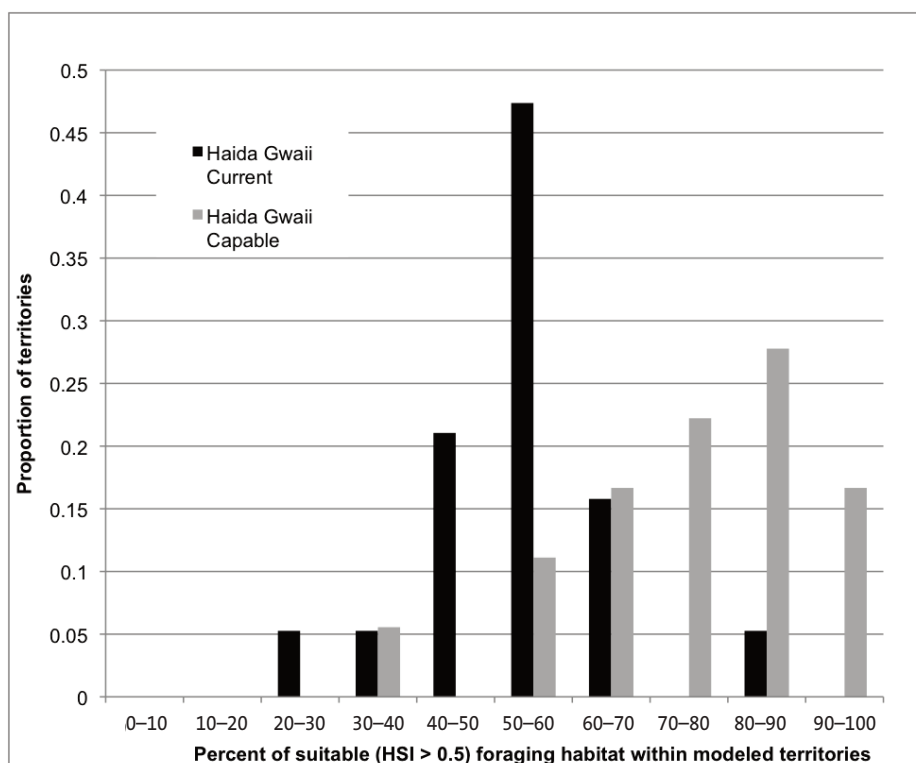


Figure 9. Estimated proportions of suitable foraging habitat within coastal goshawk territories (estimated using the territory model centred on known breeding areas) under current and historic (capable) habitat conditions on Vancouver Island ($n = 82$; territory size = 3530–4616 ha) and Haida Gwaii ($n = 19$; territory size = 7831–11 310 ha).

currently have 40–50% suitable foraging habitat (J. Smith & R. Vennesland, unpublished data). Overall, this amounts to an estimated total decline of 41% and 29% of modelled foraging habitat for Vancouver Island and Haida Gwaii territories, respectively (Figure 9).

Using information on the estimated amount of decline in overall capable foraging habitat across coastal landscapes and amounts currently available within known goshawk territories, a precautionary approach to foraging habitat management is advisable; for instance, coastal goshawk territories with $\leq 20\%$ suitable foraging habitat have a low probability of long-term occupancy, whereas territories with $\geq 60\%$ suitable foraging habitat have a high probability of long-term occupancy (Figure 8). Although high uncertainty surrounds foraging habitat requirements, consistently occupied territories generally contain 40–60% suitable foraging habitat (Figure 8).

Key Points

- Estimated coastal goshawk breeding home ranges are 3745 ha on Vancouver Island and 9160 ha on Haida Gwaii. Little data are available to accurately estimate territory-spacing patterns and breeding home range sizes for the mainland coast of British Columbia.
- Coastal goshawks forage in habitats that are similar to those used for nesting, although foraging occurs in a wider range of habitat types; these may include open and riparian habitats and high-elevation forests that lack nest platforms but have seasonally high prey availability and accessibility.
- The quality of foraging habitat depends on a combination of prey abundance and structural attributes that enable prey access.
- A positive relationship exists between breeding area occupancy and the amount of mature and old forests associated with goshawk territories.
- The amount of foraging habitat required to support breeding pairs will vary with annual fluctuations in prey, habitat quality, individual hunting abilities, and brood size.
- Consistently occupied territories generally contain 40–60% suitable foraging habitat. Coastal goshawk territories with $\leq 20\%$ suitable foraging habitat have a low probability of long-term occupancy, whereas territories with $\geq 60\%$ suitable foraging habitat have a high probability of long-term occupancy.
- The estimated amount of modelled suitable foraging habitat within all coastal goshawk territories within British Columbia is 29–40% less than it was under modelled foraging habitat conditions 250 years ago.

6 Responses of Coastal Goshawks to Breeding Area Disturbance

Two types of disturbance have the potential to affect goshawk breeding area occupancy and success, each of which occurs at a different temporal scale. First, *direct disturbance* of nesting birds through noise and visual cues can occur as a result of industrial or other activities near the nest and may cause goshawks to alter their behaviour (e.g., elevated defence and vigilance behaviours that take away from foraging time, displacement that leaves eggs or young unattended, or nest abandonment), resulting in a reduction or loss of reproductive output for a given year. Second, *indirect disturbances*, such as forest harvesting or windthrow within breeding areas, may result in reduced occupancy or reproductive output, including breeding area relocation or abandonment. Evaluating the impacts of indirect and direct disturbances to goshawks is difficult and natural factors (e.g., fluctuations in weather and abundance of prey) also influence annual occupancy patterns and reproductive output of breeding areas. In this section, we summarize the results of studies that examined the effect of disturbance types and natural factors on occupancy and reproductive patterns within goshawk breeding areas.

6.1 Direct disturbance

It is difficult to evaluate the impact of disturbance on wildlife species, and different studies often use inconsistent methods (Taylor & Knight 2003). Typically, birds perceive humans as potential predators and may depart nests in response to being approached. They may abort nesting because of this increased stress. In general, a negative relationship exists between the magnitude of disturbance experienced by a nesting bird and its breeding success. For example, disturbed birds tend to spend more time off nests, which could increase the likelihood of predation on eggs or nestlings, exposure of nests and eggs to cold temperatures or wet conditions, fewer episodes of chick feeding, premature fledging or abandonment of nestlings/fledglings, and physiological stress. Birds respond differently to different types of disturbance and also to the level of disturbance, which may be influenced by the intensity, duration, frequency, and proximity of the activity but also by the cumulative effects of multiple activities in the vicinity of a nest. Therefore, setbacks need to incorporate this dynamic by identifying larger setbacks for types and levels of activities that cause greater amounts of disturbance.²⁰

Most information on direct disturbance to goshawks comes from observational studies with small sample sizes rather than from experimental manipulations, and most of this is from Europe where *A. g. gentilis* nest closer to human activity (see reviews in Squires & Reynolds 1997; Rutz et al. 2006; Ruddock & Whitfield 2007) than goshawks in North America. Goshawks are generally most vulnerable to disturbance during the incubation and early nestling stages of breeding (Boal & Mannan 1994; Squires & Reynolds 1997; Toyne 1997; Grubb et al. 1998). Theoretically, goshawks that have invested less reproductive effort in breeding are more likely to abandon nesting attempts (i.e., during courtship, incubation, and early nestling phases) than when they have invested more reproductive effort (i.e., during the late nestling and fledgling phases; Newton 1979; Morrison et al. 2006). Once young are mobile and can relocate away from the disturbance (i.e., the fledgling phase), impacts likely diminish, although impacts during this time are also more difficult to measure.

Some key examples demonstrate differences in goshawk disturbance relative to breeding phase and distance from nest. For instance, during incubation and the early nestling stages, Toyne (1997) found that four of five goshawk breeding areas in Wales failed when logging or road-building operations occurred 0–60 m from five active nest trees. Similar

disturbances during the post-fledging periods that were 60 m, 80 m, 100 m, and 400 m from four active nests resulted in mobile young relocating away from the disturbance (Toyne 1997). Similarly, in western Italy and eastern France, timber harvesting in nest stands during egg-laying and early nestling stages caused all five nesting attempts to fail (Penteriani & Faivre 2001). Harvest activities during the late nestling and fledgling stages did not result in a measurable loss in reproduction at any of the 16 active nests monitored (Penteriani & Faivre 2001).

Human recreation (camping and trails) has also been attributed to reduced occupancy of goshawk nests in parts of California and Arizona (Speiser 1992; Beier et al. 2008; Morrison et al. 2011). For example, in the Sierra Nevada area of California, infrequently occupied territories had about twice the cumulative extent of roads and trails compared to frequently occupied territories, and this reduced occupancy rate was attributed to higher levels of human disturbance (Morrison et al. 2011).

Information on the effects of direct disturbance on breeding goshawks in coastal British Columbia is based on informal observations at goshawk nests, with several potential confounding factors, and so conclusions are difficult to discern. McLaughlin (2002) observed a coastal goshawk nest that was immediately adjacent to a newly constructed road (i.e., construction began after nest initiation) and exposed to forestry activities (blasting, hauling, falling) throughout one breeding season. During this study, the adult female was recorded to make “retreat flights” from her nest during incubation and early-nestling phases whenever a logging truck passed by the nest (< 50 m from the active road), although distant road blasting (500 m away) did not cause retreat flights (McLaughlin 2002). The adult female would alert to the noise from the logging trucks before they were visible and when trucks were approximately 200 m away and visible from her nest, she would flush off the nest. The female never habituated to the disturbance (McLaughlin 2002). Despite this behavioural effect, three young still successfully fledged from this nest.

The impacts of direct disturbance on goshawk breeding are more obvious during the early stages of breeding, when goshawks either abandon nests, or young are subjected to death attributed to starvation, predation, or chilling. However, once young fledge, it is difficult to evaluate disturbance impacts on fledgling health and survival without comparing stress-level indicators in blood, prey delivery rates, and first-year survival rates between disturbed and undisturbed nests. Moreover, individual goshawks vary in their sensitivity to noise disturbance (McClaren 2001) and differences in perceived nest vulnerability, which is influenced by landscape context features such as habitat cover/density around nests, topographic position of nest trees (Morrison et al. 2006),²¹ and nest height within trees (E. McClaren, pers. obs.). Therefore, activities that appear to have little impact near a breeding area in one year may elicit very different responses in another year because the identity of the nesting bird has changed, prey abundance has shifted, or annual weather patterns have varied. Goshawks may habituate to some types of noise disturbance, such as weaker noises farther from nests and those of a constant, predictable nature, compared to unpredictable and erratic louder noises closer to nests (McLaughlin 2002).

Some may view direct disturbances as short-term impacts that are inconsequential to the long-term outcome of goshawk breeding areas; however, goshawks have low lifetime reproductive output and lay only one clutch per breeding season (Squires & Reynolds 1997; Wiens & Reynolds 2005; Krüger 2005; Kenward 2006). In Kenward (2006), population modelling and banding recoveries provided evidence that in North America and Sweden fewer than 50% of goshawks live long enough to breed. Therefore, every year goshawks contribute young to populations is important, especially coastal goshawks

where reproductive output and occupancy rates are less than for *A. g. gentilis* and *A. g. atricapillus* (Northern Goshawk *A. g. laingi* Recovery Team 2008). Widespread and persistent disturbance has the potential to negatively affect populations if it leads to reduced occupancy and productivity of goshawk territories.

Key Points

- Direct disturbance from industrial activities can disrupt goshawk breeding and has a range of consequences, including nest abandonment.
- The impact of direct disturbance on breeding goshawks varies throughout the breeding season. The risk of nest abandonment is greatest during courtship, egg-laying, and incubation; this risk decreases during the nestling and post-fledging periods.
- Different types of direct disturbance have different impacts: closer, louder, and erratic activities are more likely to negatively affect goshawks than farther away, less severe, and regular activities.
- Individual goshawks will vary in their response to direct disturbance and direct disturbance impacts will vary among breeding areas and from year to year. Activities that seem to have little impact in one situation may elicit a very different response in another.
- Direct disturbance that is persistent over multiple years has the potential to cumulatively impact local goshawk populations.

6.2 Indirect disturbance from habitat alteration and loss within breeding areas

Forest harvesting is an indirect disturbance that may affect goshawk breeding area occupancy and reproduction. The effects of logging in and around goshawk nests have been studied by several researchers in Europe (Penteriani & Faivre 2001; Penteriani 2002; see review in Rutz et al. 2006) and in North America (see summaries by Andersen et al. 2005; Squires & Kennedy 2006; Stuart-Smith et al. 2012). For coastal goshawks, investigations have been conducted on Vancouver Island (McClaren et al. 2002; McClaren 2005) and in western Washington (Finn et al. 2002b). Most of these studies compare habitat conditions between successful or occupied goshawk nests and unsuccessful or unoccupied nests, rather than experimentally linking harvest thresholds to measures of goshawk fitness (McClaren et al. 2002; Squires & Kennedy 2006). Nearly all of these studies provide evidence that increased levels of forest removal in goshawk breeding areas (or at similar scales to the breeding area) correlate with reduced breeding area occupancy. Moser and Garton (2009) observed that detrimental weather conditions can interact with forest harvesting to exacerbate the impacts to goshawk breeding success (also see Section 7.2).

Conclusively linking the causes of variation in reproductive success to forest harvesting is limited by several confounding factors, including weather patterns, changes in prey availability, and time lag effects. It is essential to consider time lags because goshawks may continue to occupy breeding areas that become unsuitable following harvest events because of their strong fidelity to these areas (Mahon & Doyle 2005; Stuart-Smith et al. 2012).

The amount of logging that goshawks can tolerate around their nests likely depends on several factors, including habitat and prey associations, the suite of nest competitors and predators within landscapes, and the availability of suitable breeding habitat nearby. In Europe, many studies suggest goshawks can nest close to human activity, within agricultural areas, and in highly fragmented landscapes (Rutz et al. 2006); however, buffers greater than 100 m around nests in intensively harvested areas of Finland resulted in higher occupancy than when harvesting occurred less than 100 m from nests (Santangeli et al. 2012). Desimone and DeStefano (2005) examined occupancy patterns in Washington at 51 historical nest areas relative to changes in forest composition created from logging. Mid-late-aged, closed-canopy forests were significant indicators of forest conditions that supported breeding pairs, and goshawks were more likely to persist in historical nest areas with greater than 50% mid- and late-seral, closed-canopy forest within 52 ha of nests (Desimone & DeStefano 2005). In northern Idaho, Moser and Garton (2009) experimentally tested the effects of logging within goshawk breeding areas on re-occupancy and nesting success for 2 years following treatments. Eleven different breeding areas were all or partially logged after the breeding season, once adults and fledglings had left. The following year, the number of young that fledged within these breeding areas, and within 10 untreated control breeding areas, did not differ. Re-occupancy was linked, however, to the amount of suitable nesting habitat retained within 170 ha surrounding the original active nest; goshawks re-occupied breeding areas if they contained more than 39% suitable nesting habitat after logging.

Goshawks may be able to adjust the location of their breeding areas within territories in response to logging if other suitable breeding habitat is available nearby (< 1 km). For example, Penteriani and Faivre (2001) monitored 21 goshawk pairs nesting in logged and unlogged stands in central Italy and eastern France. Stands were harvested with a shelterwood system, first with a light pre-commercial thinning followed by three progressive steps of 20% removal, and then by a final 30% removal. Logging typically occurred every 2–3 years. Goshawks remained in stands where light thinning was conducted; no difference was evident in occupancy or productivity between pairs in thinned versus unthinned stands. In nest stands in which the structure was altered by more than 30%, however, 87.5% of the pairs monitored ($n = 9$ pairs) relocated to the nearest neighbouring suitable stand (< 1.5 km away; Penteriani & Faivre 2001).

In British Columbia's interior, Mahon (2009) and Mahon and Doyle (2005) examined the effects of logging trials at 40 of 93 known goshawk nest areas (represented by a circular area of 24 ha, centred on the geometric average location of all known nest trees within the area). Occupancy patterns were compared between treatment and control nest areas over the 12-year study. Mahon (2009) found no significant difference in overall occupancy between treatment areas (39%, $n = 229$) and control areas (45%, $n = 356$); however, a more subtle response was observed whereby goshawks relocated their nest sites away from recently harvested areas (see Table 5 in Stuart-Smith et al. 2012). Two main results were evident. First, as observed in other studies (Woodbridge & Detrich 1994; Stuart-Smith, et al. 2012), a lag effect was seen in goshawk response to logging. In the first 3 years after logging, goshawks continued breeding at 74% of the original nest areas, but

after 6 years, occupancy at the original nest areas had dropped to 30%. Second, goshawks exhibited a graded response that correlated to the amount of nest area logged. For nest areas that continued to be occupied after 6 years, the average portion of area logged was 18%. For unoccupied (goshawks not detected) nest areas, an average of 63% was logged. Goshawks can modify or relocate their breeding areas in response to logging; however, logging known breeding areas as well as adjacent suitable breeding areas, where goshawks may relocate after harvest disturbance, has large impacts. Mahon (2009) observed that logging occurred at 11 of the 15 new breeding area locations, preventing the establishment of stable new breeding areas. Thirty-three of these same breeding areas were re-assessed for occupancy in 2014, and goshawks were only detected at four (12%; Doyle 2014). Interestingly, these four occupied breeding areas were comprised of significantly larger (> 40 ha; t -test, $P < 0.001$) intact areas of mature old growth than the 29 unoccupied breeding areas, and with the addition of two new breeding areas located in 2014, 67% of occupied breeding areas were larger than 80 ha ($n = 6$; Doyle 2014).

Other researchers have examined the effect of reserve size on occupancy patterns. In northern California, Woodbridge and Detrich (1994) found that occupancy rates of 23 goshawk nest stands with at least 5 years of monitoring were positively correlated with total nest stand area. Occupancy rates of nest stands less than 20 ha in size were less than 50%. For nest stands approximately 40 ha in size, occupancy increased to 75–80%, and for nest stands greater than 61 ha, occupancy was nearly 100% (Woodbridge & Detrich 1994). Nest stands in this study consisted of multiple alternative nest-tree clusters of unmanaged mature forest stands surrounded by regenerating or thinned forests.

In the East Kootenay region of British Columbia, Stuart-Smith et al. (2012) also found that re-occupancy was positively related to reserve size. In this study, reserves consisting of mature or old forests (> 80 years old with canopy closure $> 40\%$), of various sizes (1 ha to > 100 ha), shapes, and distances from contiguous forest were placed around 28 active goshawk breeding areas, which were monitored before logging and for 4–10 years after logging. Study results indicated that reserve size and edge-to-area ratio were strong predictors of reserve re-occupancy (Stuart-Smith et al. 2012). Reserves greater than 100 ha in size had the highest occupancy, and reserves of less than 23 ha were not occupied for more than 2 years after logging. A negative linear relationship was evident between occupancy and the amount of hard edge (i.e., the length of reserve edge bordering regenerating forest < 40 years old, brush, talus, or water). Reserves with more than 90% of their boundary as hard edge were unlikely to be occupied after logging. The presence of spur roads and trails within the breeding area reserve did not have a significant influence on breeding area occupancy. Relationships between reserve size and edge-to-area ratios were stronger when data from the first 2 years after logging were removed from the analysis, indicating a potential lag effect and the importance of long-term monitoring in interpreting responses of goshawks to timber harvesting within breeding areas (see Figure 6 in Stuart-Smith et al. 2012).

Similar patterns have been observed for coastal goshawks. Finn et al. (2002b) analyzed habitat structure, composition, and configuration of home ranges at three spatial scales (39 ha nest area; 177 ha post-fledging area; 1886 ha home range) and examined correlations between vegetation conditions and site occupancy at 30 historical nest sites (i.e., those containing at least one goshawk and a large stick nest when discovered) on Washington's Olympic Peninsula. Of the 12 historical sites that were occupied over a 3-year monitoring period, all sites had a higher proportion of late-seral forest ($> 70\%$ canopy closure of conifer species with $> 10\%$ of the canopy trees > 53 cm diameter at breast

height), reduced stand initiation cover, and reduced landscape heterogeneity at all three scales. These same variables were also significant at the post-fledging area and home range scales for predicting occupancy. In their southeast Alaska study, Iverson et al. (1996) did not explicitly analyze relationships between occupancy and habitat attributes of breeding areas; however, based on habitat characteristics of coastal goshawk home ranges, these authors suggest harvest regimes that most closely emulate the size, frequency, and intensity of natural forest dynamic processes in time and space will most likely create landscapes which will support goshawks in the future (Iverson et al. 1996).

In comparison, harvest regimes that convert productive old-growth forests to predominantly early seral habitats will reduce the overall habitat capability and probability of goshawk persistence into the future (Iverson et al. 1996). On Vancouver Island, McClaren (2005) analyzed the effects of year and breeding area landscape type on occupancy patterns using a logistic regression analysis. She defined:

- *fragmented breeding areas* as those within isolated patches of forest greater than 50 years old, surrounded by forest 25 years old or younger, and in stands of less than 50 ha;
- *contiguous old-growth breeding areas* as those within forests greater than 120 years old, and in stands of 200 ha or larger; and
- *contiguous second-growth breeding areas* as those within forests 50–90 years old, and in stands of 200 ha or larger.

Occupancy assessments at 44 breeding areas between 1995 and 2002 showed that year ($X^2_{72} = 20.2, P = 0.005$) and landscape type ($X^2_{22} = 10.8, P = 0.005$) significantly influenced occupancy rates (McClaren 2005). Occupancy rates were significantly lower in breeding areas within fragmented landscapes relative to contiguous old-growth landscapes ($X^2_{12} = 10.6, P = 0.001$) and contiguous second-growth landscapes ($X^2_{12} = 4.5, P = 0.03$). Although occupancy rates were highest in contiguous old-growth landscapes, they were not significantly different from contiguous second-growth landscapes ($X^2_{12} = 0.8, P = 0.4$). The influence of reserve size on number of young fledged is less clear; McClaren et al. (2002) could not discern spatial patterns in the number of young fledged within goshawk breeding areas on Vancouver Island.

Indirect disturbance within goshawk breeding areas and home ranges may also lead to shifts in competitor and predator community dynamics (Hakkarainen et al. 2004; La Sorte et al. 2004; Squires & Kennedy 2006; Jiménez-Franco et al. 2011), and this may be an important factor in breeding area occupancy. Logging within and near coastal goshawk breeding areas increases edge habitats and leads to a shift from older to younger seral stage forests. Red-tailed Hawks, Great Horned Owls (*Bubo virginianus*), and Barred Owls (*Strix varia*) are predators and stick-nest competitors for goshawks (La Sorte et al. 2004; Squires & Kennedy 2006) and species that thrive in patchwork forest mosaics (Speiser & Bosakowski 1988; Johnson 1992).

Key Points

- Several studies demonstrate positive correlations between the amount of structurally mature and old forests and goshawk occupancy patterns at breeding-area scales. Relationships between habitat characteristics and demographic parameters are less clear.

Key Points

- Goshawks are known to have strong fidelity to established breeding areas, which may lead to time lags in observed impacts from logging on occupancy patterns.
- Goshawks may shift or relocate breeding areas within territories in response to harvesting. Most breeding area relocations occur less than 2 km from established breeding areas. If an alternative breeding area is unavailable, it is unlikely goshawks will be able to relocate, because neighbouring territories are often occupied and will preclude settlement by the displaced pair.
- Broad changes in forest seral stage distributions and patch sizes associated with widespread forest harvesting may lead to changes in competition and predator–prey dynamics for coastal goshawks.

7 Other Sources of Variation in Breeding Area Occupancy and Reproduction

Several factors other than forest harvesting and direct disturbance can influence goshawk occupancy and reproduction. These include individual and pair quality (i.e., the pair's ability to raise young), foraging area characteristics, annual weather conditions, and shifting or cycling prey abundance (McClaren et al. 2002; Penteriani 2002; Kenward 2006; Reynolds et al. 2006; Squires & Kennedy 2006). In some cases, several years may pass before conditions are favourable to support breeding within any given breeding area. Within coastal goshawk breeding areas on Vancouver Island and in Haida Gwaii, up to 6 years have passed between occupancy events over 17 years of monitoring. Similarly, Reynolds et al. (2005) observed 7 years to elapse between breeding events within a breeding area on the Kaibab Plateau, Arizona. Consequently, just as short-term re-occupancy of breeding areas by goshawks may represent a lag effect owing to strong site fidelity, short-term breeding area monitoring (< 10 years) that fails to detect breeding birds should not be interpreted as a failure of the specific management actions applied to a given breeding area.

7.1 Individual quality

Long-term research on reproductive output of breeding individuals within *A. g. gentilis* (Nielsen & Drachmann 2003) and *A. g. atricapillus* (Wiens & Reynolds 2005) populations has demonstrated that relatively few adult females (~15–20%) contribute approximately half of all young. The age of breeding individuals may also influence reproductive output (Reynolds et al. 1994; Krüger 2005) and the date that young fledge, which subsequently affects the survival of young (Younk & Bechard 1994). Furthermore, interactions between individual quality and habitat quality occur that influence reproductive output (Krüger & Lindström 2001; Krüger 2005). This level of information does not exist for coastal goshawk populations, although it is certain that individual quality varies and it is likely this variation influences lifetime reproductive output and interpretation of goshawk responses to management actions.

7.2 Annual and longer-term weather patterns

Fluctuations in annual weather conditions are an important factor affecting goshawk annual breeding area occupancy and success rates. Cool, wet weather in the spring may directly cause egg-chilling and nestling mortality, or it may indirectly reduce breeding productivity by limiting foraging opportunities (Kostrzewa & Kostrzewa 1990; Penteriani 1997; Bloxton 2002; Sunde 2002; Wiens et al. 2006a). Annual weather patterns can have long-term, population-scale impacts. For instance, more than 25 years of goshawk monitoring in Germany showed that cold and rainy conditions in early spring negatively affected population growth rates (Krüger & Lindström 2001). Impacts of weather conditions on goshawks have also been observed in some North American studies. Both Keane et al. (2006) and Fairhurst and Bechard (2005) speculated that short- and long-term weather conditions may combine to produce large annual variations in occupancy and breeding success. Some evidence suggests that longer-term weather patterns (e.g., Pacific Decadal Oscillations, or La Niña events) are driven, in part, by the effects of ocean currents on temperature and rainfall (Brown & Comrie 2004). In this scenario, several years may pass before conditions are suitable to support the occupancy of any given breeding area (Bloxton 2002; Stuart-Smith et al. 2012).

These patterns have also been observed for coastal goshawks, where annual variation in weather had a strong influence on breeding area occupancy (western Washington, Bloxton 2002; Vancouver Island, McClaren et al. 2002, Manning et al. 2004; Haida Gwaii, Doyle 2009). Weather conditions may also affect prey availability (i.e., change behaviours and activity levels) and foraging success through the suppression of raptor hunting behaviour in cold, wet conditions (fewer foraging flights and a reduction in prey delivered to nestlings; Olsen & Olsen 1989; Newton 1998).

7.3 Prey, predators, and competitors

In addition to weather, the annual abundance of prey within goshawk home ranges can directly affect both occupancy rates and breeding success within breeding areas. Prey availability and abundance can vary widely in response to landscape alterations, climate, and annual weather patterns (Squires & Reynolds 1997; McClaren et al. 2002; Keane et al. 2006; Reynolds et al. 2006). During the winter and into the courtship period, females must reach a critical level of body condition required for egg-laying (Marcström & Kenward 1981; Newton et al. 1983). Therefore, prey availability in late winter and early spring influences the onset of breeding each year (Keane 1999). As well, food supply can indirectly be linked to competition for nest sites, **siblicide** rates, and depredation of adults or eggs (Estes et al. 1999; Dewey & Kennedy 2001). In populations of *A. g. gentilis* (Lindén & Wikman 1983) and *A. g. atricapillus* (Doyle & Smith 1994; Erdman et al. 1998), cyclic populations of key goshawk prey species (grouse and snowshoe hare) can cause boom and bust years for goshawk occupancy and reproductive output. In other landscapes in which several prey species are abundant, however, low populations of certain prey in a given year seem to have little impact on goshawk reproduction because goshawks readily substitute other prey species in their diet (Salafsky et al. 2007). Ward and Kennedy (1996) and Dewey and Kennedy (2001) experimentally determined that goshawks have a demographic response to food supplementation, although this relationship only occurred when prey was limited in regional populations (Dewey & Kennedy 2001).

For coastal goshawks, red squirrels are a key mammalian prey species (Watson et al. 1998; Ethier 1999; Lewis et al. 2006). On Vancouver Island, red squirrel detections were positively correlated with breeding area occupancy rates between 1996 and 1999 (Pelletier

2000) and between 2003 and 2006 (Manning et al. 2007); however, Pelletier (2000) did not find a significant correlation between red squirrel detections and nest productivity.

The distribution and abundance of similar-sized, stick-nesting raptor species may also influence the distribution of breeding goshawk pairs (Kostrzewa 1996; Sánchez-Zapata & Calvo 1999; Krüger 2002; Kenward 2006). The degree to which coastal goshawk populations are limited by **inter-specific competition** for nest sites and food is unknown, although Spotted Owls, Common Ravens, Red-tailed Hawks, and Great Blue Herons have been observed using nests previously occupied by coastal goshawks.

Key Points

- Variation in the quality of individual birds, yearly weather, and local prey availability make it difficult assess the effect of management actions on either occupancy or other measures of reproductive success.
- More than 10 years of breeding area monitoring are required to adequately interpret management actions and potential influences on goshawk breeding area occupancy and success patterns.
- High precipitation and cool temperatures during courtship and nestling breeding phases may result in lower occupancy rates at breeding areas and fewer offspring.
- Annual fluctuations in key prey species for coastal goshawks may influence breeding area occupancy rates and reproductive success.
- The distribution and abundance of similar-sized, stick-nesting raptor species likely influences the distribution of breeding goshawk pairs, but the degree of inter-specific competition for nest sites in coastal goshawk populations is unknown.

8 Best Management Practices for Coastal Goshawk Breeding Areas

The following management recommendations integrate information presented in previous sections into best management practices designed to mitigate the potential impacts of resource development activities near goshawk breeding areas on the continued occupancy of those areas by goshawks. These practices were tailored specifically to forestry operations, but they could also be applied to other resource development activities that result in forest clearing, including oil and gas operations, pipeline/transmission projects, mineral extraction, and urban development. These recommendations are driven by our refined definition of the breeding area (Section 5), the estimated breeding area sizes and habitat use patterns, breeding season chronology, and response to disturbances observed in coastal British Columbia and other coastal forest ecosystems in western Washington and southeast Alaska. When data from coastal ecosystems was sparse, we also drew upon data from *A. g. atri-*

capillus populations inhabiting interior British Columbia and western North America and from *A. g. gentilis* in European populations, where long-term datasets and data from intensively monitored and disturbed populations exist.

Table 6. Conceptual framework for estimating risk of abandonment relative to breeding area reserve size used in coastal goshawk best management practices. Risk of abandonment is considered for periods over 5 years to account for a potential lag effect in goshawk response. Categories are provided for descriptive purposes; risk of abandonment is expected to show a graded response across the range of breeding area sizes.

Breeding area reserve size	Risk of breeding area abandonment	Ecological rationale of risk classification
< 46 ha	Extreme (Ineffective)	Smaller than smallest breeding area size estimate
46–76 ha	High risk	76 ha = 50th percentile breeding area size estimate; only meets the size of what approximately half the goshawks used
76–104 ha	Moderate risk	104 ha = 70th percentile breeding area size estimate
104–175 ha	Low risk	175 ha = 90th percentile breeding area size estimates; meets the size of what approximately 90% of goshawks used
> 200 ha	Minimal	Exceeds the breeding area size estimate for all but one breeding area

We present our recommendations in a conceptual “likelihood of impact” framework, based on the probability that management actions will affect the continued use of breeding areas by goshawks in the short term (from direct disturbance) or long term (from habitat alterations) (Table 6). This likelihood of impact framework should be interpreted to represent the relative risk of breeding area abandonment. The range of estimated breeding area sizes within coastal British Columbia (Table 5) served as our foundation for assessing the risk of abandonment. This framework makes the explicit assumption that a reduction of breeding area size below 200 ha will result in an increased probability of abandonment. For guidance, Table 6 provides five categories of reserve size for breeding areas, but these do not represent firm threshold boundaries because the probability of continued goshawk occupancy likely represents a linear, positively increasing relationship with breeding area size. Responses by goshawks to different breeding area reserve sizes are expected, on average, to follow this pattern of abandonment for a large number of breeding areas. The response at any specific breeding area may vary depending on many factors, such as the behaviour of individual birds, foraging habitat quality and prey availability, weather, and local predators and competitors, as discussed in Section 7. Data to verify and quantify this response across the full range of breeding area sizes estimated for coastal British Columbia are not available; however there is strong evidence of discontinued occupancy by coastal goshawks within small breeding areas (< 50 ha), avoidance by coastal goshawks of nesting within 200 m of clearcut edges (see Section 5), and significantly lower occupancy rates in fragmented landscapes on Vancouver Island compared to contiguous landscapes (McClaren 2005). As discussed in Section 6, the positive relationship between occupancy and increased breeding area size has been observed in several other regions (Woodbridge & Detrich 1994; Penteriani & Faivre 2001; Mahon 2009, Stuart-Smith et al. 2012, Doyle 2014). Furthermore, because

coastal goshawks are federally designated as “threatened” and are provincially red-listed, the low-risk options presented here are consistent with a precautionary approach when full scientific certainty is unachievable (Government of Canada 2003) and will best ensure retention of functional breeding areas.

8.1 Summary of best management practices for coastal goshawk breeding areas

Table 7 summarizes key management factors associated with maintaining occupancy at goshawk breeding areas in coastal British Columbia. A more detailed discussion of each element is provided in the following sections.

Table 7. Summary of best management practices for maintaining long-term occupancy at coastal goshawk breeding areas in British Columbia.

Objectives	1) Maintain nesting and post-fledging area habitat at known coastal goshawk breeding areas to support continued reproduction at these areas over many years. 2) Avoid resource development activities near active breeding areas that may affect the breeding behaviours and breeding success of coastal goshawks.
Defining the breeding area	Once an active breeding area is identified, a qualified environmental professional should conduct an extensive search to locate the active and alternative nests and to assess suitable breeding habitat around those nests to define the actual shape and configuration of the breeding area.
Reserve size	• Reserve size is the most important factor in determining whether the breeding area will continue to be occupied over the long term. Reserves less than 46 ha in size are unlikely to support long-term occupancy and are considered ineffective, whereas those more than 175 ha in size have a high likelihood of supporting long-term occupancy. • Reserve size refers to the total amount of suitable breeding habitat within the breeding area; although unsuitable habitats may be included within reserves to achieve connectivity between nest trees or to reduce edge effects, these habitats do not contribute toward meeting overall reserve size objectives.  Reserve size and risk of breeding area abandonment
Reserve design	• Maximize the number of nests located during breeding area assessments that are included within the reserve (normally all known nests). • Maintain connectivity between all nest trees retained within breeding area reserves (i.e., nest trees should not be isolated from each other by harvesting) with suitable breeding habitat where possible, and with lower-quality forested habitat if no other options are available. • Minimize edge effects to nest trees by retaining at least 200 m of suitable breeding habitat, if possible, and if not, potential recruitment habitat. • Minimize edge effects to breeding area reserves by avoiding reserve designs with high edge–area ratios, such as long linear reserves or reserves with sections less than 200 m wide. • Maintain connectivity between breeding area reserves and adjacent forest stands to increase the effective size of the reserve and to provide forested linkages to foraging habitat beyond the breeding area. • Design reserve boundaries to minimize the risk of windthrow.

Table 7. (Continued)

Minimizing direct disturbance	• Avoid industrial activities within no-work zones surrounding active nests (50 m, 100 m, 500 m, or 1000 m, depending on the type of activity) during the breeding period from February 15 to September 15. If this entire period is not practicable, avoid the most sensitive period from March 15 to July 1.  Risk of nest failure or abandonment from direct human activity and noise disturbance
Managing multiple breeding areas	• Resource professionals need to share coastal goshawk breeding area information within a natural resource district or timber supply area. • Consider the range of existing breeding area reserve sizes within the same natural resource district or timber supply area when designing new reserves. • Manage known breeding areas at a low or minimal risk of abandonment.
Existing planning tools and strategies	Reduce the impact of breeding area reserves on timber supply by overlapping them, where suitable breeding habitat exists, with areas constrained for other reasons, such as: • Wildlife Habitat Features • Old Growth Management Areas • Ungulate Winter Ranges • Wildlife Habitat Areas for other species • Wildlife Tree Patches and Riparian Reserves • Land Use Planning Objectives • Inoperable forest and unstable terrain • Visual Quality Objectives • Parks and Protected Areas
Landscape-level foraging habitat considerations	• Breeding area occupancy and long-term population viability of goshawks within coastal forests are also influenced by habitat conditions and prey availability at scales larger than the breeding area. • Although some uncertainty exists regarding foraging habitat requirements, a precautionary approach to goshawk foraging habitat management suggests that maintaining 40–60% suitable foraging habitat within territories will result in long-term occupancy of breeding areas. • Insufficient data preclude the determination of a minimum threshold for the amount of foraging habitat surrounding breeding areas below which the probability of occupancy becomes so low that protecting them is not warranted.

Intended as flexible guidelines rather than prescriptive requirements, forest managers can adapt these practices to the unique environmental conditions and competing management objectives at each breeding area. In some cases, meeting the optimal condition for each factor in the practice may be precluded by existing landscape patterns, timber harvest history, or the operational constraints of current and future resource development. Nevertheless, a reasonable probability exists that goshawks will continue to occupy the breeding area if most nest trees are protected and an adequate breeding area size is maintained.

8.2 Defining the breeding area

When a goshawk breeding area is first located, the indicator of activity is often of a defensive adult(s) protecting its nest or young. This information is insufficient to define the breeding area extent and a formal survey by a qualified environmental professional is required. The objectives of the initial breeding area survey are to: (1) locate all existing nest trees, and

(2) document the forest characteristics at nest sites and determine the extent of similar forest in the surrounding area. Appendix 4 contains detailed protocols for conducting breeding area surveys and the qualifications that personnel require to perform these surveys.

Table 8. Recommended minimum distance to keep activities away from the nearest active coastal goshawk nest site during periods of high and moderate risk (February 15 to September 15).

Likelihood of impact	Activity	Timing restriction distance ^a
Very high	• Repeated low-elevation flights (< 305 m) • Blasting • Continuously operating drilling rig or well flaring	More than 1 km
High	• Road-building (without blasting) • Logging • Pipeline and well-site construction • Detonation of seismic charges • Wind tower construction • Seismic line cutting (mechanical)	More than 500 m
Moderate	Hauling and road maintenance (logs, heavy equipment, etc.)	More than 100 m
Low	• Silviculture activities (e.g., planting and site preparation) • Seismic line cutting (manual) • Industrial and public traffic	More than 50 m, where practicable. Individual birds and young may be affected by these activities. If birds seem distressed (i.e., continuous calling, birds staying away from active nest, aggressive behaviours toward people/equipment, etc.), then the activity should cease until at least July 1.

^a This is the distance from the known nest site within which timing restrictions should be applied. Any activities that are farther away than this distance do not need to apply timing restrictions. Individual goshawks will vary in their response to disturbance levels, depending on several factors that include habitat characteristics, breeding chronology, age, and individual variation.

Sometimes, a goshawk nest is discovered during active resource development operations. In this case, operations need to shut down until a systematic survey can be conducted to help inform how the area will be managed. Options for reserves may be limited, depending on the forest that has already been harvested, but potential reserves may still exist and the recommendations outlined in this section should be considered. If the nest is active when discovered, the nest is protected under the *Wildlife Act* (Section 1.3.3) until young have fledged from nests (July 1–August 1). Nevertheless, to ensure goshawks are able to successfully fledge young and young are able to survive until they disperse from the breeding area, suspend operations that fall under the types of activities and within distances from active nests as described in Table 8 until September 15 (or as determined by follow-up monitoring). If this is not possible, delay activities with a very high and high likelihood of impact (see Table 8) until July 1, when the most sensitive incubation and early nestling periods are typically complete. If operations continue without following guidelines provided in Table 8, nest abandonment and (or) mortality of the young may result (see Section 6.1), which may be considered a contravention of the *Wildlife Act* and the Canadian *Species At Risk Act*.

8.3 Reserve design

Based on the information presented within these best management practices, the amount and configuration of habitat that is protected within the breeding area is probably the most important factor associated with maintaining long-term occupancy of breeding areas by goshawks. Figure 10 provides our interpreted relative risk of abandonment, which is based on breeding area size estimates for coastal goshawks in British Columbia ($n = 63$) (see also Table 5, Section 5.3). Various environmental and ecological factors may cause the sizes of breeding areas in other ecosystems to differ (e.g., estimates for breeding areas sizes in interior British Columbia using the same analytical approach were smaller).



Figure 10. The relative risk of breeding area abandonment associated with breeding area reserve sizes following logging. Reserve sizes less than ~50 ha are likely to be ineffective at maintaining long-term occupancy by coastal goshawks.

To design breeding area reserves that will maintain long-term goshawk occupancy in coastal British Columbia, we recommend the following best management practices.

- **Conduct an extensive search for current and alternative nest trees.** After an active breeding area is identified, a qualified environmental professional should conduct an extensive search to locate the active and alternative nests, and then assess suitable breeding habitat around those nests. This information defines the actual shape and configuration of the breeding area.
- **Delineate breeding area reserves that are an effective size.** Reserve size is the most important factor we identified in determining whether the breeding area will continue to be occupied over the long term. Reserves of less than 46 ha are unlikely to support long-term occupancy and are considered ineffective, whereas those of more than 176 ha have a high likelihood of supporting long-term occupancy. Calculate the size of breeding area reserves as the area offering suitable breeding habitat (i.e., forest similar in composition to those surrounding the nest trees). Although habitats with no or low suitability for breeding may be included within reserves (i.e., to provide connectivity among nest trees or to reduce edge effects), do not include these areas in the calculation of the effective breeding area size.
- **Maximize the number of nest trees included within the breeding area reserve.** Nest trees are key features that define the extent of the breeding area. Where possible, include all nest trees in the breeding area reserve.
- **Maximize the amount of suitable breeding habitat within breeding area reserves.** This includes suitable nesting habitat (i.e., forest that offers future nest trees) and post-fledging area habitat. As much as possible, include stands with characteristics similar to the areas in which the nest trees are found (e.g., stand height, composition, slope position).
- **Maintain connectivity between all nest trees within breeding area reserves.** Design reserves in which forested habitat connects all known nest trees. Although this may include areas of low-quality breeding habitat, these areas are important if they provide the only opportunity to maintain connectivity among nest trees. Do not include any type of forest clearing between nest trees within breeding area reserves.
- **Minimize edge effects and windthrow risk to nest trees and to overall breeding area reserves.** Where possible, maintain at least 200 m of forested habitat

around all nest trees. Avoid reserve designs with shapes that have a large proportion of edge (e.g., long linear reserves) and with sections less than 200 m wide. Incorporate design considerations that minimize windthrow.

- **Maintain connectivity between breeding area reserves and adjacent forest stands.** Connect breeding area reserves to adjacent forest stands. This will provide forested linkages both to foraging habitat beyond the breeding area and to future alternative breeding area habitat in the event the current breeding area becomes unsuitable or degraded (e.g., through natural disturbances such as fire or windthrow).

8.4 Minimizing direct disturbance: Timing restrictions

Goshawks are susceptible to direct disturbance from human activity and noise near active nests during the breeding season (see Section 6.1). Disturbed birds tend to spend more time off nests, which could increase the likelihood of predation on eggs or nestlings, exposure of eggs or juveniles to cold temperatures or wet conditions, fewer food deliveries to juveniles, abandonment of juveniles, premature fledging, and physiological stress. Goshawks do not normally breed successfully every year; their breeding lifetime is short and they raise only a few young during each breeding attempt. Thus, direct disturbance can have substantial impacts on a pair's lifetime reproductive output. The degree to which human activities cause disturbance to breeding goshawks depends on the intensity, duration, frequency, and proximity of the activity to an active nest. Also, consider the cumulative effects of multiple activities in the vicinity of active nests. Furthermore, the sensitivity of goshawks to disturbance varies throughout the breeding season (Figure 11). Generally, activities that are quieter, regular, and farther from active nests will cause less disturbance than those that are louder, erratic, and closer to active nests; however, responses will vary among different goshawks, site conditions, and in different years.



Figure 11. Risk of nest failure or abandonment from direct human activity and noise disturbance, relative to coastal goshawk breeding chronology.

Table 8 presents recommended timing restrictions and setback distances that incorporate this dynamic by identifying larger setbacks for types and levels of activities causing greater amounts of disturbance. Ideally, do not conduct activities that could disturb breeding goshawks within 100 m, 500 m, or 1 km (depending on the activity) of active nests from February 15 through September 15 (for coastal breeding chronology see McClaren 2005; McClaren et al. 2005; Doyle 2005b). If this is not practical, avoid the most sensitive portion of the breeding season between March 15 and July 1 (orange and red on Figure 11), or schedule activities closest to the breeding area (or active nest) to occur outside this high-risk period (Figure 11).

Timing restrictions for a given year need not be applied if nest occupancy surveys (see Appendix 4) indicate a breeding area is not occupied by adult birds or their young. Goshawk breeding areas may be used for decades, and coastal goshawks may be difficult to detect. Therefore, occupancy should be carefully assessed before proceeding with activities that may disturb breeding birds. This means that breeding areas should be sur-

vayed multiple times by qualified environmental professionals before determining a breeding area is unoccupied (see Appendix 4 for recommended survey protocols).

8.5 Managing multiple breeding areas

When implementing these best management practices, ensure that breeding areas are not managed independently from one another and that the cumulative impacts of resource activities in the region (e.g., natural resource district, timber supply area, tree farm licence) and levels of breeding area protection are considered. For example, if several breeding areas in a region are already undergoing management to a high risk of abandonment, this would elevate the importance of managing newly discovered breeding areas to a lower risk of abandonment to mitigate impacts to local populations.

Ultimately, the number of stable breeding areas supporting long-term occupancy and reproductive output is a key factor in supporting sustainable goshawk populations. Given the relative difficulty in locating breeding areas, it is likely that many breeding areas are unknowingly affected. This places a greater importance on maintaining occupancy at as many known breeding areas as possible. Given the conservation rank of the coastal goshawk, we recommend managing known breeding areas to a minimal or low risk of breeding area abandonment.

Ideally, land managers should distribute breeding area reserves across a range of habitat types within a region to provide geographic representation across factors such as biogeoclimatic variants, stand types, elevation, slope, and aspect. This management strategy should disperse risk relative to factors such as regional prey variation, fire and pest outbreaks, and different forest management approaches. In areas where goshawks are known to occur but breeding areas are unknown, forest harvest plans should also attempt to provide conditions that will facilitate future breeding area establishment (i.e., large enough forest extents and suitable breeding habitat).

8.6 Foraging area considerations

Breeding area occupancy and long-term population viability of goshawks within coastal forests are influenced by habitat conditions and prey availability at scales larger than the breeding area. Although relatively abundant information exists on the types of habitat used by goshawks for foraging and by their prey, little information is available that actually quantifies the amount and spatial arrangement of foraging habitat required to support a breeding pair of goshawks. Data from patterns of territory occupancy observed on Haida Gwaii and Vancouver Island suggest that territories with less than 20% suitable foraging habitat have the highest risk of territory abandonment, regardless of the breeding area reserve size. Territories with greater than 60% suitable foraging habitat have the lowest risk of territory abandonment (see Section 5.4, Figure 8). Requirements likely vary regionally and temporally in response to fluctuations in prey availability, habitat quality, brood size, and by individuals (hunting efficiency, experience). For example habitat modelling simulations using 20%, 40%, and 60% foraging habitat requirements found that the 40% foraging habitat level resulted in patterns of territory outputs that best matched current inventory information and predictions of goshawk biologists. The current draft recovery strategy for the Northern Goshawk *laingi* subspecies recommends 45–61% of a territory be maintained in suitable foraging habitat, depending on the conservation region (Parks Canada 2014). These values are based on the 50th percentile of foraging habitat amount observed in consistently occupied territories (see Appendix 3). Although some uncertainty surrounds foraging habitat requirements, a precautionary approach to goshawk foraging

habitat management suggests that maintaining between 40 and 60% suitable foraging habitat within territories (see Section 5.4 and Figure 8) should result in long-term occupancy of breeding areas.

Another important issue for managing goshawk foraging habitat is the scale at which it is managed—specifically, whether to manage foraging habitat for individual territories, or at larger scales such as landscape units, which include multiple territories. When breeding areas are known, it makes sense to manage foraging habitat targets and spatial distributions relative to known breeding areas. However, when breeding areas are not known but landscapes contain suitable breeding and foraging habitats, it may make sense to apply foraging habitat targets at landscape-unit levels to ensure that opportunities for goshawk territories remain. This management approach will help meet distribution goals for coastal goshawk population recovery (for further details, see: Northern Goshawk *Accipiter gentilis laingi* Recovery Team [2008] and B.C. Ministry of Forests, Lands and Natural Resource Operations & B.C. Ministry of Environment [2013]).

Key Points

- The effectiveness of a breeding area reserve design in maintaining long-term occupancy by goshawks depends on the size, location, and configuration of the reserve.
- Management actions at one breeding area should not be made in isolation from management actions at other known breeding areas in the region as these decisions may cumulatively impact local goshawk populations.
- Most coastal goshawk breeding areas should be protected with reserves that have a low or minimal risk of abandonment.
- Distribute breeding area reserves to provide geographic representation across biogeoclimatic variants and other landscape factors; this will help to distribute risk across forest ecosystems with different prey types, fire and pest regimes, and resource development pressures.
- Long-term breeding area occupancy and reproductive output depends on sufficient foraging habitat supply within territories. Although uncertainty surrounds foraging habitat requirements, consistently occupied territories generally contain 40–60% suitable foraging habitat.
- When breeding area locations are not known but landscapes contain suitable breeding and foraging habitats, apply foraging habitat targets at larger sub-regional scales, such as landscape units, to ensure opportunities for goshawk territories remain.

9 Strategic and Operational Planning Considerations

Although managing for goshawk breeding areas does add another factor into resource management plans and can create operational constraints, designing effective breeding area reserves that maintain the occupancy of goshawks at their original breeding areas is the best approach to minimize both planning time and constraints over the long term. Maintaining occupancy in the original breeding area eliminates management concerns for goshawk breeding habitat over the remaining territory (e.g., 3700 ha on Vancouver Island). If breeding area reserves are not large enough to maintain breeding area occupancy, goshawks will likely respond by shifting their breeding area to nearby forests and these new breeding areas may subsequently conflict with future harvest operations. This can result in additional planning, operational costs and delays, and impacts to the goshawks. In north-central British Columbia, 11 of 15 breeding area shifts over 5 years overlapped with additional proposed harvesting (Mahon 2009), and this pattern has also been observed in coastal areas of the province (E.L. McClaren, pers. obs.).

9.1 Co-location of breeding area reserves

The timber supply impacts from goshawk breeding area reserves may be reduced by overlapping these reserves with one or more constrained areas existing under current legislative frameworks (see Figures 12 and 13 for examples). Computer-based programs such as Marxan (Ardron et al. 2010) can help to determine the possible contribution of individual areas and

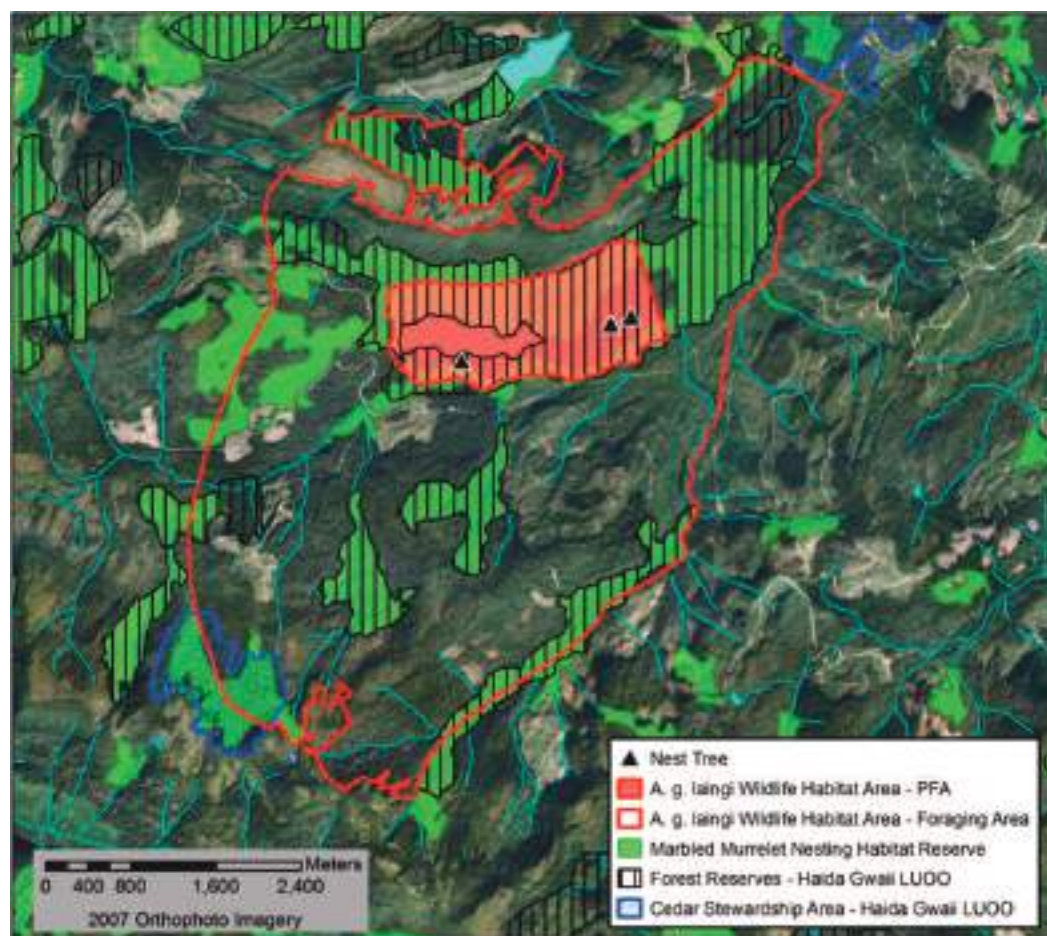


Figure 12. Example of using Wildlife Habitat Areas and Haida Gwaii land-use planning objectives for other values (Marbled Murrelet nesting habitat, forest reserves, cedar stewardship areas) to protect coastal goshawk breeding areas and foraging habitat and to minimize overall timber supply impacts.



Figure 13. Example of using Wildlife Habitat Areas, Ungulate Winter Ranges, and Old Growth Management Areas on Vancouver Island to protect coastal goshawk breeding areas and foraging habitat while minimizing overall timber supply impacts. The areas at the top of the ridge and east of the Wildlife Habitat Area down to the lake were not included in the reserve because they did not provide suitable breeding habitat.

whole networks toward meeting overall planning objectives (e.g., ecosystem-based management on the central coast; Horn et al. 2009a). Here we provide some examples of other legislative and planning tools that may assist in achieve breeding area reserve objectives.

- **Wildlife habitat features** – A wildlife habitat feature may include a localized feature such as a coastal goshawk nest. Generally, the scale of these features does not provide sufficient protection for coastal goshawk breeding area habitat; however, it may assist to meet reserve design targets and assist in protecting foraging habitat. No wildlife habitat features have been identified to date, but work to legally establish wildlife habitat features is ongoing.
- **Old growth management areas** – On provincial Crown forest land, varying percentages of old (and sometimes mature) forest must be retained within each biogeoclimatic zone in each landscape unit. If goshawk breeding areas meet the criteria for old-growth forest (typically many of them do), these areas could be spatially designated as Old Growth Management Areas. Having larger old forest reserves will also benefit other old growth-associated species that inhabit coastal forests and provide places for biologically important features such as snags, which are difficult to retain within harvested areas. Spatially locating these reserves offers more certainty for forest planners than managing for aspatial targets only and avoids the necessity of frequently calculating old-growth percentages to check balances against targets; however, aspatial reserves may assist in meeting foraging area targets within goshawk territories.
- **Wildlife tree patches** – Current legislation contains various requirements for the percentage of forest in wildlife tree patches, which must be established within each landscape unit to help maintain biodiversity in landscapes managed for forestry. Although usually quite small (< 5 ha), these patches could be combined with other areas (e.g., inoperable, riparian areas) to contribute to a breeding area reserve and thus help offset the impact of larger goshawk breeding area reserves on the timber harvesting land base.

- Riparian reserves – Most riparian reserves are narrower than the breeding areas used by goshawks; however, incorporating these reserves with breeding area reserves could help offset the impact of larger goshawk breeding area reserves on the timber harvesting land base.
- Wildlife habitat areas for other species at risk – Wildlife habitat areas can be legally established for species considered to be at risk in British Columbia. Areas designated for other species (e.g., the Marbled Murrelet [*Brachyramphus marmoratus*]; Doyle 2006a) may also provide suitable coastal goshawk habitat, and so the co-location of these reserves could serve to protect multiple species that share similar habitat associations.
- Ungulate winter ranges – All provincial Crown forest land contains requirements to manage for ungulate winter ranges. In some areas, goshawk breeding and foraging areas may be overlapped with ungulate winter ranges, particularly those for Black-tailed deer (*Odocoileus hemionus columbianus* and *Odocoileus hemionus sitkensis*) and Roosevelt Elk (*Cervus elaphus roosevelti*). In addition, goshawk foraging habitat may overlap with mountain goat habitat (*Oreamnos americanus*).
- Land use planning objectives – Land Use Orders often provide several opportunities for co-locating suitable coastal goshawk breeding and foraging habitats with other Land Use Planning objectives. For example, within the Central and North Coast and South Coast Land Use Orders,²² coastal goshawks are a focal species, and direction is provided to overlap focal species habitats with other land use objectives, such as site-series surrogate targets, important fisheries watersheds, grizzly bear habitat, old-forest representation, and red- and blue-listed plant communities. On Haida Gwaii, the Land Use Plan provides direct protection for known and future goshawk breeding areas but also provides protection for several other values that may capture suitable goshawk breeding and foraging habitats. These include Marbled Murrelet habitat, rare ecosystems, riparian corridors, and visual quality objectives.
- Inoperable forest – Most timber supply areas contain large tracts of forest that are currently uneconomical to harvest. Although some of this forest is unsuitable as goshawk breeding areas because it is steep and rocky or located at high elevations, suitable areas that are inoperable (e.g., owing to access) could be incorporated into breeding area reserves to offset impacts to the timber harvesting land base. Reserves could also be established adjacent to inoperable areas to help reduce nest-reserve edge effects and increase breeding area reserve connectivity to adjacent stands.
- Unstable terrain – Forest stands located on unstable terrain are rarely logged because of the high likelihood of landslides following timber harvesting or road construction. Such areas may make suitable goshawk breeding area reserves, or may be located adjacent to reserves to help meet reserve size and configuration objectives.
- Visual quality objectives – Some timber supply areas have objectives to maintain scenic areas and (or) meet visual sensitivity class objectives. Meeting these objectives involves minimizing the visual impact of forest harvesting by limiting the size, shape, or number of cutblocks, or increasing the retention within them. If the forest offers suitable goshawk breeding habitat, these areas can make good places for breeding area reserves, especially when they are at lower elevations.
- Parks and protected areas – Where suitable breeding and (or) foraging habitats exist within provincial or federal protected areas, these areas can greatly assist in meeting coastal goshawk habitat objectives outside the timber harvesting land base.

Although the list above includes the most common and potentially applicable opportunities for co-locating goshawk habitat management with other types of land use zoning, additional opportunities may exist or develop in the future. When considering co-location

opportunities, it is critical to assess the suitability of those areas as goshawk habitat and how they contribute to overall reserve design. In some cases, these types of constrained areas may not actually provide suitable goshawk habitat.

9.2 Windthrow considerations in reserve design

Within coastal regions, the combination of tall trees, heavy rainfall, shallow soils, and mountainous terrain makes many areas susceptible to windthrow. For a goshawk breeding area reserve to persist for long time periods, windthrow risk should be explicitly considered. We recommend a windthrow assessment (Stathers et al. 1994) that takes into account prevailing wind speed and direction, topography, terrain, vegetation characteristics, and rainfall to ensure that any planned forest clearing (roads or cutblocks) adjacent to reserves minimizes the risk of windthrow impacts on the integrity of the breeding area reserve.

9.3 Habitat quality evaluation: Operational and strategic considerations

The Northern Goshawk *A. g. laingi* Recovery Team and Habitat Recovery Implementation Group developed standardized habitat models for the coastal goshawk across this subspecies' range in coastal British Columbia (Smith & Sutherland 2008; Smith 2012; Mahon et al. 2015). The three models developed were: (1) a nesting habitat model, (2) a foraging habitat model, and (3) a territory model. The territory model assesses the amount, quality, and distribution of nesting and foraging habitat relative to average goshawk territory sizes and spacing patterns, and is used for analysis purposes, not to predict actual territory locations. The nesting habitat and foraging habitat models are based on the habitat suitability index methodology and are intended to assess the relative quality, amount, and distribution of goshawk breeding and foraging habitats in coastal British Columbia. Habitat rating output from these models represents relative values suitable for comparisons across the study area and for comparing habitat supply (i.e., predicted number of territories) under different management scenarios. At stand-level scales (i.e., one to several forest cover polygons; 10–500 ha), model use should be limited to the nesting and foraging model outputs. Normally, emphasis should be placed on the nesting model because it targets a more specific range of habitat conditions than the foraging model. It is generally inappropriate to use any of the territory model outputs at stand-level scales. Examples of stand-level uses of the nesting and foraging habitat model outputs include:

- stratifying areas for goshawk inventory efforts;
- aiding in the delineation of conservation areas around known goshawk breeding areas; and
- evaluating the relative impacts of different cutblock locations on goshawk habitat.

Although the accuracy of both the nesting and foraging models met *a priori* benchmarks set by the Northern Goshawk *A. g. laingi* Recovery Team, a significant error rate still exists in model outputs at stand-level scales related to the accuracy of the underlying forest cover data. Therefore, any use of model outputs should be consistent with generally accepted practices and limitations associated with using forest cover data for other forest management and habitat management activities. We strongly recommend that use of the model outputs at stand-level scales include verification of model predictions, including ground verification (habitat quality assessments) and air photo assessment. Breeding area reserve design should include a field assessment by a qualified environmental professional.

9.4 Enhancing forest structure to promote goshawk habitat characteristics

The guidelines within this best management practice are focused on managing forest attributes that currently support breeding by coastal goshawks. Nevertheless, we recognize that land managers may wish to implement stand-level silviculture practices in previously harvested stands (rather than rely on natural succession) to more quickly recruit structural attributes that support breeding and (or) foraging by coastal goshawks. Negrave and Stewart (2010) provided several recommendations to promote mature and old structural attributes in younger coastal Douglas-fir and associated ecological communities that are also applicable to enhance breeding and foraging habitat attributes for coastal goshawks (e.g., structural stage ≥ 5 , high canopy closure, subcanopy flyways, strong lateral branches). Some of these habitat enhancement approaches include the following:

- Extended rotations – Rotations exceeding 80 years of age are more likely to recruit mature and old-growth features into stands (Blackwell et al. 2002). Extended rotations used over relatively small portions of landscapes (i.e., 5–10%, distributed in multiple patches) may benefit goshawks because breeding areas constitute approximately 5% of the overall breeding territory.
- Clustered retention – Several silvicultural systems may be appropriate for this strategy, including true single-tree selection systems, group selection systems, and irregular and group shelterwood systems with reserves. These systems may provide legacy trees that offer suitable nest sites in stands in which the regenerating trees are still too young to offer suitable branch structures for nests. Retention of trees and other forest structure (e.g., snags and coarse woody debris) can also benefit goshawk foraging habitat. All of these systems should use clearly defined cutting rules and post-harvest structural targets to ensure the retained trees meet the structural requirements for goshawk nest sites or other desired characteristics.
- Irregular (commercial) thinning – This regime should increase light penetration to the forest floor, promoting regeneration of understorey attributes desirable for enhancing goshawk prey diversity. Clearly defined cutting rules and post-harvest structural targets are required; otherwise, this may lead to removing attributes that are structurally important in stands.
- Snag recruitment – Standing dead wood can be recruited by girdling trees or by retaining areas of *Phellinus weirii* (laminated root rot). Live conifers can be inoculated with various fungi to promote decay, but the success of this approach remains uncertain (Filip et al. 2011; but see Manning & Manley 2014). Snags provide important plucking posts for goshawks and enhance prey diversity (i.e., woodpeckers, small owls).
- Coarse woody debris recruitment – Larger pieces of “cull” trees and woody debris within harvest openings should be retained onsite, rather than taken to landings or other collection areas. Coarse woody debris provides important plucking posts for goshawks, enhances prey diversity, provides important nutrients for soil replenishment, and provides a growth medium for seedlings, understorey vegetation, and fungi.
- Juvenile spacing and pruning – Juvenile spacing is similar to commercial thinning but is applied to younger stands and can speed the recruitment of suitable stand structure elements, such as subcanopy flyways, into uniform second-growth stands.

Some coastal goshawk studies have focused specifically on stand treatments to promote desired structural attributes for nesting. On Washington’s Olympic Peninsula, a 245–445 stem per hectare cut was recommended in 30- to 35-year-old stands (Finn et al. 2002a) to accelerate development of suitable nesting characteristics. In the same area, Bloxton (2002) recommended thinning smaller trees to open up the understorey without

reducing canopy closure. Lilieholm et al. (1993) recommended the use of commercial thinning at 350 stems per hectare to enhance nest site attributes. Bosakowski et al. (1999) promoted the retention of remnant mature forest patches in cutblocks to provide nesting trees within younger stands (40–54 years old) as they regenerate.

To enhance foraging habitat attributes for coastal goshawks, work on Haida Gwaii (Doyle 2006c) and on the Olympic Peninsula (Bloxtun 2002) identified silvicultural activities that promote the abundance of prey. On the Olympic Peninsula, variable density thinning was used to create a diversity of prey niches, and snags were retained as foraging perches and to promote various goshawk prey that forage and nest within tree cavities. In general, Manning et al. (2002) recommended maintaining and recruiting forest structure (e.g., snags, wildlife tree patches, and coarse woody debris) in harvested areas to provide foraging habitat after regenerating stands begin to self-thin.

Key Points

- Where possible, locate breeding area reserves for coastal goshawks in forests that currently provide attributes used for nesting and foraging. Maintaining currently suitable breeding habitat is likely more effective at protecting goshawks than using habitat enhancement or restoration techniques to create forests with favourable attributes.
- In landscapes where historical harvest patterns have made them unsuitable for goshawks, it may be appropriate to use silviculture practices to improve the structural attributes of forests for goshawks, sooner than would be achieved through natural succession.
- Some silviculture practices that may benefit goshawks include extended rotations, clustered retention, irregular thinning, snag and coarse woody debris recruitment, or juvenile spacing and pruning.

10 Knowledge gaps and key research questions

We based the best management practices presented here on the best science currently available to us, including study results from British Columbia and from the broader scientific literature. In our opinion, these recommendations for managing breeding areas are robust, given the substantial data on which they are based, the similarity in findings between our two study areas, and the consistency of our results with other studies in coastal forest ecosystems and more broadly within North America. Nevertheless, as with any management advice regarding wildlife habitat and industrial development, some uncertainty still surrounds the expected outcomes associated with these recommendations. Some important knowledge gaps related to the management of goshawk breeding areas in coastal British Columbia include the following:

- Foraging habitat requirements and use patterns, especially in winter, and relationships between foraging habitat amount and territory occupancy and reproductive output.

- Relationships between breeding area size and occupancy especially at larger breeding area sizes (it is known that a negative relationship exists between occupancy and small breeding area sizes).
- Fledgling dispersal patterns.
- Breeding density and territory size within the North and South Coast regions.
- Demographic parameters, including average life span and number of reproductive years, survivorship, emigration and immigration, and dispersal and recruitment rates.
- Assessment of key factors that may affect demography, such as competition for nests sites; siblicide; depredation of adults, young, and eggs; and disease and climate, in addition to habitat effects.
- Changes in predator-prey dynamics as a result of introduced species, especially in Haida Gwaii.
- Level of threat posed by human persecution and disturbance near nest sites.
- Gene flow among conservation regions, effects of genetic isolation on population viability (especially for Haida Gwaii), and refinement of the range boundaries for *A. g. laingi*.
- The long-term effects of climate change on various factors affecting coastal goshawks, including changes in forest structure, prey, and weather, and how these changes affect habitat use and population variables.

For a complete discussion of knowledge gaps that have been identified for coastal goshawks, refer to the Northern Goshawk *A. g. laingi* Recovery Strategy (Northern Goshawk *A. g. laingi* Recovery Team 2008) and provincial management plan (B.C. Ministry of Forests, Lands, and Natural Resource Operations & B.C. Ministry of Environment 2013).

Our lack of understanding around the amount and composition of foraging habitat at the home-range scale and how this affects goshawk breeding area occupancy and reproductive output (McClaren et al. 2002; Daust et al. 2010) is a key factor limiting the development of an effective approach to landscape management for the species. Numerous studies suggest that foraging habitat is an important factor, but elucidating relationships between it and goshawk fitness is difficult because of the different spatial scales used for analysis in various studies and the different prey species and habitat associations in different ecosystems. A noticeable gap in this area concerns habitat and prey requirements in winter, a time when few data have been collected in coastal British Columbia (Iverson et al. 1996; McClaren 2005) or for goshawks in western North America generally (but see Mahon 2009; Stephens 2001). Addressing foraging habitat questions has important implications for forest management at the landscape scale because, ultimately, effective goshawk habitat management requires both adequate nesting habitat at the breeding-area scale and foraging habitat at larger spatial scales.

Another important knowledge gap relates to demographic information (i.e., goshawk survival, reproduction, immigration, and emigration). Our focus on habitat (with prey abundance and availability as part of habitat) is based on the generally accepted assumption that habitat is a primary limiting factor to individual goshawks and to goshawk populations (see Squires & Kennedy 2006). If other factors affecting goshawk populations (e.g., climate, disease, or competition with other species) are significant or become significant, then detailed demographic information will be required to adjust management regimes. Few data are currently available on adult and juvenile survival or immigration and emigration in coastal British Columbia (McClaren 2005), or for goshawks in western North America generally (but see Andersen et al. 2005; Wiens et al. 2006b; Reynolds & Joy 2006). Ultimately, these data are required to accurately determine population trends

and inform recovery targets. Without demographic data, managers often assume that occupancy at a subset of known breeding areas is an index of population trends (Patla 2005; Squires & Kennedy 2006; but see Hargis & Woodbridge 2006; Bruggeman et al. 2011), but this may not be the case.

Obtaining good demographic information requires telemetry data from a large sample of adult and juvenile goshawks, collected over a long time period, which in turn requires knowledge of breeding area locations to trap and place radio or satellite transmitters on adult and juvenile birds; however, these data are rarely collected because of the difficulty and expense involved in obtaining them. A strong demographic study that also takes into account the range of genetic isolation observed between populations (Sonsthagen et al. 2012) coupled with breeding area occupancy monitoring (Hargis & Woodbridge 2006) and habitat assessments, would be a vital contribution to our understanding of goshawks and how to monitor them. Such a study would also allow quantification of breeding area turnover rates and the selection of new breeding areas within territories, in response to both natural and anthropogenic factors. It would also help quantify how the forest composition and prey availability in goshawk territories affects breeding area productivity. Before embarking on such a study, however, it is important to ensure sufficient sample sizes are obtainable to address the research questions. Placing geolocator tags on animals likely impacts survival rates and for rare species, this may have serious population-level consequences.

Understanding goshawk–habitat relationships in the context of a changing climate will become increasingly important. Several authors suggest that weather, particularly wet spring weather, is one of the primary factors influencing goshawk reproductive success (Newton 1979; Krüger & Lindström 2001; Moser & Garton 2009). Increased precipitation can cause the death of nestlings through hypothermia (Kostrzewa & Kostrzewa 1990), and can also reduce adult hunting success (Olsen & Olsen 1989). The climate in several coastal regions has become warmer and wetter in spring over the past few decades (Doyle 2008; Utzig 2011), and if this trend continues as predicted (Utzig 2011), goshawk populations may be significantly affected. Warmer spring weather may also lead to earlier hatching and increased densities of black flies, which are known to kill goshawk nestlings through blood loss (Doyle 2008). These factors suggest that goshawks may be sensitive to changes in climate, as well as to industrial operations. This emphasizes the importance of including climate variables along with habitat variables when investigating occupancy and productivity patterns in goshawks. This uncertainty also suggests that a conservative approach to goshawk habitat management, which reduces the potential additional stress from climate, would be prudent.

Within the Haida Gwaii study area, introduced species may substantially threaten coastal goshawks, by directly and (or) indirectly reducing prey abundance. Relevant introduced species include Sitka Black-tailed Deer (*Odocoileus hemionus sitkensis*), Red Squirrels, Raccoons (*Procyon lotor*), and rats (*Rattus* spp.). In particular, browsing by deer is believed to dramatically reduce forage and cover for grouse and other prey species. Introduced species do not appear to pose a threat to goshawks within the Vancouver Island, South Coast, and North Coast conservation regions. Instead, coastal goshawks may use some introduced species, such as Eastern Cottontail Rabbits (*Sylvilagus floridanus*; Nagorsen 2002) as prey. Changes in predator-prey dynamics resulting from introduced species and from species that have expanded or shifted their ranges (eg. Barred Owls in coastal B.C.), is unclear range wide.

Key Points

- An important knowledge gap involves the amount and composition of foraging habitat at the home-range scale and how this affects goshawk fitness. Effective goshawk habitat management will require both adequate breeding habitat at the breeding-area scale and adequate foraging habitat at the home-range or territory scale.
- Demographic information will become increasingly important if factors other than habitat (e.g., climate, disease, genetic isolation, competition) are, or become, significant factors driving goshawk population dynamics.
- On Haida Gwaii, we are uncertain what impacts introduced species are having on goshawk populations and their prey.

11 Data Management

We conclude by highlighting the importance of an effective framework for reporting, storing, and sharing coastal goshawk nest location, occupancy, and reproductive data, which is currently lacking. These data, when consistently collected (i.e., using standardized occupancy assessments), constitute the basis for effective monitoring and future refinement of these best management practices as more information becomes available. An appropriate data storage and management framework should have the ability to:

- distribute the most current data to stakeholders in a timely manner;
- control access to data (i.e., sensitive nest site data should only be released to legitimate stakeholders); and
- update databases annually, at a minimum.

Although the B.C. Conservation Data Centre should be the repository for these data within the province, not all data are reported, especially from Privately Managed Forest Lands. This database offers a secure and accessible repository for species-at-risk data and is used by provincial employees to assess the status of populations. Coastal goshawk nest-location databases, which are maintained within forest companies or regional government offices, tend to be lost when personnel transfer positions or tenures change. Sharing coastal goshawk nest-location data and the co-management of goshawk populations within shared tenure areas can be problematic and lead to the management of breeding areas on an individual rather than on a regional basis. Likewise, in many areas of the province, multiple resource industries operate on the same land base (e.g., energy, forestry, and mining) and so co-operative planning among industries is critical to the effective management of goshawk breeding areas and populations. With shared information, industry and government managers can determine the overall distribution of management risk for goshawk breeding areas in their region and then take action if this distribution is heavily skewed toward high risk management (high probability of breeding area abandonment). Without a co-ordinated effort to manage multiple breeding areas, regional goshawk populations may suffer from a “tragedy of the commons” scenario, whereby most breeding areas are managed at a high likelihood of abandonment. The provincial

Wildlife Species Inventory database²³ offers a suitable location for the storage and tracking of coastal goshawk survey and monitoring data. It is as important to record where goshawks are not detected as well as where they are found. This database already offers an accessible repository for species-at-risk data and would be a logical choice for storing information on areas surveyed or monitored for goshawks.

Key Points

- An effective framework for reporting, storing, and disseminating goshawk nest location and occupancy data is critical to the effective, long-term implementation and refinement of these best management practices.
- Currently, two provincially managed databases (i.e., B.C. Conservation Data Centre and Wildlife Species Inventory) offer a central location to store nest location, breeding area occupancy, and survey data that can be used for status assessments and distributed to various qualified environmental professionals in a timely manner, where appropriate.
- Co-operative planning among resource industries around the management of coastal goshawk breeding and foraging areas is critical to the effective management of goshawk populations.

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Notes

1. Terms appearing in bold typeface are defined in the Glossary (see Appendix 1).
2. British Columbia Conservation Data Centre. 2014. B.C. Species and Ecosystems Explorer website. B.C. Ministry of Environment, Victoria, B.C. <http://a100.gov.bc.ca/pub/eswp/> (Accessed July 2015).
3. Forest Practices Code of British Columbia Act, [RSBC 1996] Chapter 159. http://www.bclaws.ca/Recon/document/ID/freeside/00_96159_01 (Accessed August 2015).
4. Forest and Range Practices Act, [RSBC 2002] Chapter 69. http://www.bclaws.ca/Recon/document/ID/freeside/00_02069_01 (Accessed August 2015).
5. Federal Register, Volume 77, No. 148, August 1, 2012. Department of the Interior, Fish and Wildlife Service, 50 CFR Part 17. Endangered and threatened wildlife and plants; listing the British Columbia distinct population segment of the Queen Charlotte Goshawk under the Endangered Species Act; Final Rule. http://www.fws.gov/alaska/fisheries/endangered/goshawk/pdf/goshawk_final_rule.pdf (Accessed 2015).
6. See the Alaska Department of Fish and Game website: <http://www.adfg.alaska.gov/index.cfm?adfg=specialstatus.akconcern>.
7. See Washington Department of Fish and Wildlife "Washington state species of concern lists" [website]: <http://wdfw.wa.gov/conservation/endangered/lists/search.php?searchby=StateStat&search=SC&orderby=AnimalType,CommonName/> (Accessed August 2015).
8. See the CITES website: <http://ec.gc.ca/cites/listedesespeces-specieslist/index.cfm?lang=en&fuseaction=species.swDetailedInfo&code=1472&src=text>.
9. Species at Risk Act, [SC 2002] Chapter 29. <http://laws-lois.justice.gc.ca/eng/acts/S-15.3/FullText.html> (Accessed August 2015).
10. National Accord for the Protection of Species at Risk. 1996. See: <https://www.registrelep-sararegistry.gc.ca/6B319869-9388-44D1-A8A4-33A2F01CEF10/Accord-eng.pdf> (Accessed August 2015).
11. Canada–British Columbia Agreement on Species at Risk. 2005. http://www.sararegistry.gc.ca/virtual_sara/files/agreements/aa_Canada-British_Columbia_agreement_on_species_at_risk_0805_e.pdf (Accessed August 2015).
12. Land Act, [RSBC 1996] Chapter 245. http://www.bclaws.ca/civix/document/id/complete/statreg/96245_01 (Accessed August 2015).
13. Wildlife Act, [RSBC 1996] Chapter 488. http://www.bclaws.ca/Recon/document/ID/freeside/00_96488_01 (Accessed August 2015).
14. Park Act, [RSBC 1996] Chapter 344. http://www.bclaws.ca/civix/document/id/complete/statreg/96344_01 (Accessed August 2015).
15. See: Central and North Coast Order. http://www.for.gov.bc.ca/tasb/slrp/lrmp/nanaimo/cencoast/docs/CNC_consolidated_order.pdf and South Central Coast Land Use Orders. B.C. Ministry of Forests, Lands and Natural Resource Operations, Nanaimo, B.C. <http://www.for.gov.bc.ca/tasb/slrp/lrmp>

/nanaimo/cenocoast/docs/2013/scc/South-Central-Coast-Order-Consolidated-Version-2013.pdf
(Accessed August 2015).

16. Environment Canada. Canadian climate normals 1981–2010 [website]. Data for Campbell River A, B.C. http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=145&lang=e&StationName=Campbell+River&SearchType=Contains&stnNameSubmit=go&dCode=1 (Accessed August 2015).
17. Environment Canada. Canadian climate normals 1981–2010 [website]. Data for Sandspit A, B.C. http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=367&lang=e&StationName=Sandspit&SearchType=Contains&stnNameSubmit=go&dCode=4&dispBack=1 (Accessed August 2015).
18. All estimates of error provided are standard error unless specified otherwise.
19. The historical landscape condition represents the amount of suitable habitat that could have been available historically if all currently capable habitats were suitable. Capable habitat includes all “forest” capable of having the characteristics outlined by Mahon et al. (2015) for high or moderate suitability foraging habitat, even if it is currently unsuitable. Capable foraging habitats would not include those areas within landscapes that are permanently non-forested, such as water bodies, rock, ice, etc., or low-productivity, open canopy forests, such as most forested bogs.
20. See the Environment Canada “Avoidance Guidelines” website: <http://ec.gc.ca/paom-itmb/default.asp?lang=En&n=AB36A082-1> (Accessed August 2015).
21. Ibid.
22. Op. cit., see endnote 15.
23. Species Inventory Web Explorer: <http://www.env.gov.bc.ca/wildlife/wsi/siwe.htm>.
24. Forest and Range Practices Act, Government Actions Regulation, B.C. Reg. 582/2004, Section 11(1). http://www.bclaws.ca/civix/document/id/complete/statreg/582_2004#section11 (Accessed August 2015).
25. Foresters Act, [SBC 2003], Chapter 19. http://bclaws.ca/civix/document/id/complete/statreg/03019_01 (Accessed August 2015).
26. Endangered Species Act of 1973. <http://www.nmfs.noaa.gov/pr/laws/esa/text.htm> (Accessed August 2015).

References

- Alaska Department of Fish and Game. 1998. State of Alaska species of special concern. Division of Wildlife Conservation, Juneau, AK.
- _____. 2006. Our wealth maintained: a strategy for conserving Alaska’s diverse wildlife and fish resources. Alaska Department of Fish and Game, Juneau, AK. http://www.adfg.alaska.gov/static/species/wildlife_action_plan/cwcs_main_text_combined.pdf (Accessed August 2015).
- American Ornithologists’ Union. 1957. Checklist of North American birds. 5th ed. American Ornithologists Union, Baltimore, MD.
- Andersen, D.E., S. DeStefano, M.I. Goldstein, K. Titus, C. Crocker-Bedford, J.J. Keane, R.G. Anthony, & R.N. Rosenfield. 2003. The status of Northern Goshawks in the western United States. The Wildlife Society, Bethesda, MD. Wildlife Society Technical Review 04-1. <http://wildlife.org/wp-content/uploads/2014/05/NorthernGoshawks04-1.pdf> (Accessed July 2015).
- _____. 2005. Technical review of the status of Northern Goshawks in the western United States. *Journal of Raptor Research* 39(3):192–209.
- Ardron, J.A., H.P. Possingham, & C.J. Klein (editors). 2010. Marxan good practices handbook. Version 2. Pacific Marine Analysis and Research Association, Vancouver, B.C. <http://pacmara.org/wp-content/uploads/2010/07/Marxan-Good-Practices-Handbook-v2-2010.pdf> (Accessed July 2015).
- Banner, A., W. MacKenzie, S. Haeussler, S. Thompson, J. Pojar, & R. Trowbridge. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. B.C. Ministry of Forests, Research Branch, Victoria, B.C. Land Management Handbook No. 26. <https://www.for.gov.bc.ca/hfd/pubs/docs/Lmh/Lmh26.htm> (Accessed July 2015).
- Bartzen, B. 2000. The effectiveness of stand-watches in the nestling and fledgling phases of Northern Goshawks (*Accipiter gentilis laingi*). [Unpublished Biology Cooperative Education report]. University of Victoria, Victoria, B.C.
- Beebe, F.L. 1974. Field studies of the *Falconiformes* of British Columbia. B.C. Provincial Museum, Victoria, B.C. Occasional Paper No. 17.
- Beier, P., & J.E. Drennan. 1997. Forest structure and prey abundance in foraging areas of Northern Goshawks. *Ecological Applications* 7(2):564–571.

- Beier, P., E.C. Rogan, M.F. Ingraldi, & S.S. Rosenstock. 2008. Does forest structure affect reproduction of northern goshawks in ponderosa pine forests? *Journal of Applied Ecology* 45(1):342–350. <http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2007.01409.x/full> (Accessed August 2015).
- Beyer, H.L. 2004. Hawth's analysis tools for ArcGIS. <http://www.spatialecology.com/htools/> (Accessed July 2015).
- Blackwell, B.A., H.A. Hedberg, & J.A. Trofymow. 2002. Stand structure and species composition in chronosequences of forests on southern Vancouver Island. Canadian Forest Service, Pacific Forestry Centre, Victoria, B.C. Information Report BC-X-395. <http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/21075.pdf> (Accessed August 2015).
- Bloxton, T.D., Jr. 2002. Prey abundance, space use, demography, and foraging habitat of Northern Goshawks in western Washington. MSc thesis. University of Washington, Seattle, Wash.
- Boal, C.W., & R.W. Mannan. 1994. Northern Goshawk diets in Ponderosa pine forests on the Kaibab Plateau. *Studies in Avian Biology* 16:97–102.
- Bond, R.M., & R.M. Stabler. 1941. Second-year plumage of the goshawk. *Auk* 58:346–349.
- Bosakowski, T., B. McCullough, F.J. Lapansky, & M.E. Vaughn. 1999. Northern Goshawk nesting on a private industrial forest in western Washington. *Journal of Raptor Research* 33:240–244.
- B.C. Ministry of Environment, Lands and Parks, & B.C. Ministry of Forests. 1999. Managing identified wildlife: Procedures and measures. Forest Practices Code of British Columbia, Victoria, B.C. <http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/other/wild/> (Accessed August 2015).
- B.C. Ministry of Forests, Lands and Natural Resource Operations, & B.C. Ministry of Environment. 2013. Management plan for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) in British Columbia. Victoria, B.C. <http://a100.gov.bc.ca/pub/eirs/finishDownloadDocument.do?subdocumentId=9371> (Accessed July 2015).
- B.C. Ministry of Forests, Mines and Lands. 2010. The state of British Columbia's forests, 3rd ed. Forest Practices and Investment Branch, Victoria, B.C. https://www.for.gov.bc.ca/hfp/sof/2010/SOF_2010_Web.pdf (Accessed July 2015).
- B.C. Ministry of Forests and Range, & B.C. Ministry of Environment. 2010. Field manual for describing terrestrial ecosystems. 2nd ed. Forest Science Program, Victoria, B.C. Land Management Handbook No. 25. <http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh25-2.htm> (Accessed July 2015).
- B.C. Ministry of Sustainable Resource Management. 2001. Inventory methods for raptors. Version 2. Terrestrial Ecosystems Task Force, Resources Inventory Committee, Victoria, B.C. Standards for Components of British Columbia's Biodiversity No. 11. https://www.for.gov.bc.ca/hts/risc/pubs/tebiodiv/raptors/version2/rapt_ml_v2.pdf (Accessed July 2015).
- B.C. Ministry of Water, Land and Air Protection. 2004. Procedures for managing identified wildlife. Version 2004. Victoria, B.C. <http://www.env.gov.bc.ca/wld/frpa/iwms/procedures.html> (Accessed August 2015).
- Brown, L., & D. Amadon. 1989. Eagles, hawks and falcons of the world. Volume 2. McGraw-Hill Book Company, New York, NY.
- Brown, D.P., & A.C. Comrie. 2004. A winter precipitation “dipole” in the western United States associated with multi-decadal ENSO variability. <http://onlinelibrary.wiley.com/doi/10.1029/2003GL018726/full> (Accessed October 2015).
- Bruggeman, J.E., D.E. Andersen, & J.E. Woodford. 2011. Northern Goshawk monitoring in the western Great Lakes Bioregion. *Journal of Raptor Research* 45:290–303.
- Bunnell, F.L., L.L. Kremsater, & E. Wind. 1999. Managing to sustain vertebrate richness in forests of the Pacific Northwest. *Environmental Reviews* 7:99–146.
- Burg, T.M., A.J. Gaston, K. Winker, & V. Friesen. 2005. Rapid divergence and postglacial colonization in western North American Steller's Jays (*Cyanocitta stelleri*). *Molecular Ecology* 14(12):3745–3755.
- _____. 2006. Effects of Pleistocene glaciations on population structure of North American Chestnut-backed Chickadees. *Molecular Ecology* 15(9):2409–2419.
- Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, & M.C.E. McNall. 1990. The Birds of British Columbia. Volume II: Non-passerines – Diurnal birds of prey through woodpeckers. Royal B.C. Museum, Victoria, B.C. and Canadian Wildlife Service, Delta, B.C.
- Canadian Marbled Murrelet Recovery Team. 2003. Marbled Murrelet conservation assessment 2003, Part B: Marbled Murrelet Recovery Team advisory document on conservation and management. Canadian Wildlife Service, Delta, B.C. Working Document No. 1. <http://www.sfu.ca/biology/wildberg/bertram/mamurt/PartB.pdf> (Accessed August 2015).
- Chytyk, P., & K. Dhanwant. 1997. 1996 Northern Goshawk population inventory of the Queen Charlotte Islands/Haida Gwaii. [Unpublished report]. B.C. Ministry of Environment, Lands and Parks, Smithers, B.C.

- _____. 1999. 1998 Northern Goshawk (*Accipiter gentilis laingi*) population inventory of the Queen Charlotte Islands/Haida Gwaii. [Unpublished report]. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch, Smithers, B.C. Final Report.
- Clough, L.T. 1994. Nesting habitat selection and productivity of Northern Goshawks in west-central Montana. MSc thesis, University of Montana, Missoula, MT.
- Coast Forest Conservation Initiative. 2012. Maintaining the integrity of Northern Goshawk nesting and post-fledging areas in the ecosystem based management plan area of coastal British Columbia: guidance for forest professionals. [Unpublished report]. Campbell River, B.C. http://www.coastforestconservationinitiative.com/pdfNS/CFCI_Goshawk%20GMAs-GuidanceforProfessionalsJune22_2012.pdf (Accessed August 2015).
- College of Applied Biology & Association of BC Forest Professionals. 2009. Managing species at risk in British Columbia: guidance for resource professionals. Victoria, B.C. <https://www.cab-bc.org/files/SAR%20Paper.pdf> (Accessed August 2015).
- Committee on the Status of Endangered Wildlife in Canada. 2000. COSEWIC assessment and update status report on the Northern Goshawk *laingi* subspecies *Accipiter gentilis laingi* in Canada. Ottawa, ON. http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_northern_goshawk_e.pdf (Accessed August 2015).
- _____. 2013. COSEWIC assessment and status report on the Northern Goshawk *Accipiter gentilis laingi* in Canada. Ottawa, ON. http://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_autour_palombes_northern_goshawk_1213_e.pdf (Accessed August 2015).
- Cooper, J.M., & V. Stevens. 2000. A review of the ecology, management and conservation of the Northern Goshawk in British Columbia. B.C. Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C. Wildlife Bulletin No. B-101. <http://www.env.gov.bc.ca/wld/documents/statusrpts/b101.pdf> (Accessed August 2015).
- Darling, L. 2010. Evaluating Northern Goshawk wildlife habitat areas: selecting monitoring indicators. B.C. Ministry of Forests, Lands and Natural Resource Operations, Forest and Range Evaluation Program, Victoria, B.C. FREP Extension Note No. 15. https://www.for.gov.bc.ca/ftp/hfp/external/!publish/FREP/extension/FREP_Extension_Note_15.pdf (Accessed August 2015).
- Daust, D., L. Kremsater, C. Apps, K. Brunt, A. Burger, F. Doyle, K. Dunsworth, L. Dupuis, P. Friele, G. MacHutchon, T. Mahon, E. McClaren, V. Michelfelder, B. Pollard, D. Seip, J.D. Steventon, & L. Waterhouse. 2010. Focal species risk thresholds for B.C.'s North and Central Coast. Integrated Land Management Bureau, Nanaimo, B.C. Report to the Joint Coastal Land and Resource Forum Technical Liaison Committee. https://cortescommunityforestcoop.files.wordpress.com/2012/03/focal_species_risk_thresholds.pdf (Accessed August 2015).
- Daw, S.K., & S. DeStefano. 2001. Forest characteristics of northern goshawk nest stands and post-fledging areas in Oregon. *Journal of Wildlife Management* 65:59–65.
- Daw, S., S. DeStefano, & R.J. Steidl. 1998. Does survey method bias the description of Northern Goshawk nest-site structure? *Journal of Wildlife Management* 62(4):1379–1384.
- Demarchi, D.A. 2011. The British Columbia ecoregion classification. 3rd Ed. B.C. Ministry of Environment, Ecosystem Information Section, Victoria, B.C. <http://www.env.gov.bc.ca/ecology/ecoregions/> (Accessed August 2015).
- Desimone, S.M., & S. DeStefano. 2005. Temporal patterns of Northern Goshawk nest area occupancy and habitat: a retrospective analysis. *Journal of Raptor Research* 39(3):310–323.
- Desimone, S.M., & D.W. Hays. 2004. Northern Goshawk (*Accipiter gentilis*). In: Management recommendations for Washington's priority species. Vol. IV. Birds. E. Larsen, J.M. Azerrad, & N. Nordstrom (technical editors). Washington Department of Fish and Wildlife, Olympia, WA. pp. 6-1 to 6-16. <http://wdfw.wa.gov/publications/00026/wdfw00026.pdf>
- Dewey, S.R., & P.L. Kennedy. 2001. Effects of supplemental food on parental-care strategies and juvenile survival of Northern Goshawks. *Auk* 118(2):352–365.
- Dickson, R. 2001. The effect of time of day on detection rates in broadcast surveys for Queen Charlotte Goshawks (*Accipiter gentilis laingi*). [Unpublished Biology Cooperative Education report]. University of Victoria, Victoria, B.C.
- Dorner, B., & C. Wong. 2003. Natural disturbance dynamics in coastal British Columbia. Coast Information Team, Victoria, B.C. [Unpublished report]. <http://www.for.gov.bc.ca/tasb/slrp/citbc/b-NatDist-DornerWong-May03.pdf> (Accessed August 2015).
- Doyle, F.I. 2003. Biological review and recommended interim strategy direction for Northern Goshawks on Haida Gwaii/Queen Charlotte Islands. [Unpublished report]. B.C. Ministry of Water, Land and Air Protection, Smithers, B.C.

- _____. 2004a. Managing for goshawks in TFL39 on Haida Gwaii/Queen Charlotte Islands. [Unpublished report]. Weyerhaeuser Ltd., Nanaimo, B.C. FIA Project 6224020. <https://www.for.gov.bc.ca/hfd/library/FIA/2004/FIA2004MR027.pdf> (Accessed August 2015).
- _____. 2004b. Blue Grouse habitat on Haida Gwaii. [Unpublished report]. Habitat Conservation Trust Fund, Victoria, B.C. <https://www.for.gov.bc.ca/hfd/library/FIA/2004/FIA2004MR061.pdf> (Accessed August 2015).
- _____. 2005a. Ground-truthing Northern Goshawk and Marbled Murrelet habitat suitability models and conducting goshawk nesting surveys in Gwaii Haanas National Park Reserve and Haida Heritage Site: Year 2. Parks Canada, Queen Charlotte City, B.C.
- _____. 2005b. Breeding Success of the goshawk (*A. g. laingi*) on Haida Gwaii/Queen Charlotte Islands: is the population continuing to decline? South Moresby Forest Replacement Account. FIA Project 6453014. https://www.for.gov.bc.ca/hfd/library/fia/2006/LBIP_6453014.pdf (Accessed August 2015).
- _____. 2006a. Managing for goshawks on the north coast: field verification of the overlaps in goshawk and Marbled Murrelet habitat suitability ranking. B.C. Ministry of Water, Land and Air Protection, Smithers, B.C. <http://marbledmurrelet.forrex.org/sites/marbledmurrelet.forrex.org/files/docs/Goshaw-MaMu-Habitat-Overlap.pdf> (Accessed August 2015).
- _____. 2006b. Goshawks in Canada: population responses to harvesting and the appropriateness of using standard bird monitoring techniques to assess their status. *Studies in Avian Biology* No. 31:135–140.
- _____. 2006c. When do naturally regenerating and pre-commercially thinned second-growth forests attain attributes that will support Northern Goshawk (*laingi* subspecies) and Marbled Murrelets on Haida Gwaii? [Unpublished report]. Wildlife Dynamics Consulting, Telkwa, B.C.
- _____. 2008. Goshawk (*A. g. laingi*) population status on Haida Gwaii 2008. [Unpublished report]. Gwaii Forest Society and Western Forests Products Ltd.
- _____. 2009. Breeding success of the goshawk (*A. g. laingi*) on Haida Gwaii/Queen Charlotte Islands 2008. FIA Project No. 6658009. https://www.for.gov.bc.ca/hfd/library/FIA/2008/LBIP_6658009.pdf (Accessed August 2015).
- _____. 2012. Haida Gwaii Goshawks (*A. g. laingi*) 2012. [Unpublished report]. Parks Canada, Vancouver, B.C. Contract # 5P429-11-007.
- _____. 2013. Haida Gwaii Goshawks (*A. g. laingi*) 2013. [Unpublished report]. BC Timber Supply (BCTS), Husby Forest Products Ltd., Parks Canada, TAAN Forest LP.
- _____. 2014. Post mountain pine beetle: the status of Northern Goshawk breeding areas in the Nadina Forest District. [Unpublished report]. Canfor, Houston, B.C. and B.C. Ministry of Forest, Lands and Natural Resource Operations, Burns Lake, B.C.
- Doyle, F.I., & J.M.N. Smith. 1994. Population responses of Northern Goshawks to the 10-year cycle in numbers of snowshoe hares. *Studies in Avian Biology* 16:122–129.
- _____. 2001. Raptors and scavengers. In: *Ecosystem dynamics of the boreal forest: the Kluane project*. C.J. Krebs, S. Boutin, & R. Boonstra (editors). Oxford University Press, New York, NY. pp. 377–404.
- Doyle, F.I., L. Waterhouse, B. Wijdeven, M. Todd, R. Vennesland, & C. Bergman. 2012. Why has the Sooty Grouse population declined on Haida Gwaii, British Columbia, Canada? Poster presented at the North American Ornithological Conference, August 14–18, 2012.
- Drennan, J.E., & P. Beier. 2003. Forest structure and prey abundance in winter habitat of Northern Goshawks. *Journal of Wildlife Management* 67:177–185. <http://www.jstor.org/stable/3803073> (Accessed August 2015).
- Duncan P., & D.A. Kirk. 1995. COSEWIC status report on the Queen Charlotte Goshawk *Accipiter gentilis laingi* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON.
- Dunster, J., & K. Dunster. 1996. Dictionary of natural resource management. University of British Columbia. Vancouver, B.C.
- Erdman, T.C., D.F. Brinker, J.P. Jacobs, J. Wilde, & T.O. Meyer. 1998. Productivity, population trend and status of Northern Goshawks, *Accipiter gentilis atricapillus*, in northeastern Wisconsin. *Canadian Field Naturalist* 112:17–27.
- Estes, W.A., S.R. Dewey, & P.L. Kennedy. 1999. Siblicide at Northern Goshawk nests: does food play a role? *Wilson Bulletin* 111:432–436.
- Ethier, T.J. 1999. Breeding ecology and habitat of Northern Goshawks (*Accipiter gentilis laingi*) on Vancouver Island: a hierarchical approach. MSc thesis, University of Victoria, B.C.

- Fairhurst, D.G., & M.J. Bechard. 2005. Relationship between winter and spring weather and Northern Goshawk (*Accipiter gentilis*) reproduction in northern Nevada. *Journal of Raptor Research* 39(3):229–236.
- Filip, G., K. Chadwick, P. Zambino, D. Omdal, A. Ramsey-Kroll, C. Schmitt, H. Maffei, A. Saavedra, W. Rall, & C. Parks. 2011. Seven- to 14- year effects of artificially inoculating live conifers to promote stem decay and subsequent wildlife use in Oregon and Washington forests. U.S. Department of Agriculture Forest Service, Forest Health Protection, Pacific Northwest Region, Portland, OR. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5327687.pdf (Accessed August 2015).
- Finn, S.P. 2000. Multi-scale habitat influences on northern goshawk occupancy and reproduction on Washington's Olympic Peninsula. MSc thesis, Boise State University, Boise, ID.
- Finn, S.P., J.M. Marzluff, & D.E. Varland. 2002a. Effects of landscape and local habitat attributes on Northern Goshawk site occupancy in western Washington. *Forest Science* 48(1):427–436.
- Finn, S.P., D.E. Varland, & J.M. Marzluff. 2002b. Does Northern Goshawk breeding occupancy vary with nest-stand characteristics on the Olympic Peninsula, Washington? *Journal of Raptor Research* 36(4):265–279.
- Flatten, C.J., & E.L. McClaren. 2003. Size and color variation of Northern Goshawks from southeast Alaska and Vancouver Island [Abstract]. In: Raptor Research Foundation, 2003 Annual Meeting - Northern Goshawk Symposium, Anchorage, AK.
- Flatten, C., K. Titus, & R. Lowell. 2001. Northern Goshawk monitoring, population ecology and diet on the Tongass National Forest. Alaska Department of Fish and Game, Division of Wildlife Conservation, Juneau, Alaska. Annual Research Performance Report, Federal Aid Study SE-4-2-6. http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/federal_aid/goshawk.pdf (Accessed August 2015).
- Forsman, E.D., & A.R. Giese. 1997. Nests of Northern Spotted Owls on the Olympic Peninsula, Washington. *Wilson Bulletin* 109(1):28–41. <http://www.jstor.org/stable/4163772> (Accessed August 2015).
- Francis, A., & W.B. Wall. 2011. Summary of Northern Goshawk territory monitoring 2011. [Unpublished report]. Western Forest Products Inc.
- Gaston, A.J., T.E. Golumbia, J-L. Martin, & S.T. Sharpe (editors). 2008. Lessons from the Islands: introduced species and what they tell us about how ecosystems work. Proceedings from the Research Group on Introduced Species 2002 Symposium, Queen Charlotte City, Queen Charlotte Islands, B.C. Canadian Wildlife Service, Environment Canada, Ottawa, Ont. http://rgis.cefe.cnrs.fr/Publications/nouveautés/lessons_of_islands_english.pdf (Accessed August 2015).
- Good, R.E. 1998. Factors affecting the relative use of Northern Goshawk (*Accipiter gentilis*) kill areas in south-central Wyoming. MSc thesis. University of Wyoming, Laramie, WY. pp. 10–153.
- Government of Canada. 2003. A framework for the application of precaution in science-based decision making about risk. National Library of Canada, Ottawa, ON. <http://www.pco-bcp.gc.ca/docs/information/publications/precaution/precaution-eng.pdf> (Accessed August 2015).
- Gowgaia Institute. 2007. Forest economy trends and economic conditions on Haida Gwaii. Gowgaia Institute, Queen Charlotte City, Haida Gwaii, B.C. <http://www.spruceroots.org/Booklets/ForTrends.pdf> (Accessed August 2015).
- Green, R.N., & K. Linka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. B.C. Ministry of Forests, Victoria, B.C. Land Management Handbook No. 28. <http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh28.htm> (Accessed August 2015).
- Greenwald, D.N., D.C. Crocker-Bedford, L. Broberg, K.F. Suckling, & T. Tibbitts. 2005. A review of Northern Goshawk habitat selection in the home range and implications for forest management in the western United States. *Wildlife Society Bulletin* 33(1):120–148.
- Grubb, T.G., L.L. Pater, & D.K. Delaney. 1998. Logging truck noise near nesting Northern Goshawks. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fort Collins, CO. Research Note RMRS-RN-3. http://www.fs.fed.us/rm/pubs/rmrs_rn003.pdf (Accessed August 2015).
- Hakkarainen, H., S. Mykrä, S. Kurki, R. Tornberg, & S. Jugell. 2004. Competitive interactions among raptors in boreal forests. *Oecologia* 141(3):420–424.
- Hall, L.S., P.R. Krausman, & M.L. Morrison. 1997. The habitat concept and a plea for standard terminology. *Wildlife Society Bulletin* 25:173–182.
- Hall, P.A. 1984. Characterization of nesting habitat of goshawks (*Accipiter gentilis*) in northwestern California. MSc thesis. Humboldt State University, Arcata, CA.
- Hargis, C.D., & B. Woodbridge. 2006. A design for monitoring Northern Goshawks at the bioregional scale. *Studies in Avian Biology* 31:274–287.

- Harrower, W.L. 2007. Nesting requirements of the Northern Goshawk (*Accipiter gentilis atricapillus*) in southeastern British Columbia. MSc thesis. University of Victoria, B.C. <https://dspace.library.uvic.ca/handle/1828/2513> (Accessed August 2015).
- Harrower, W.L., K.W. Larsen, & K.A. Stuart-Smith. 2010. Movements and resource selection of fledgling goshawks in montane forests of southeastern British Columbia. *Journal of Wildlife Management* 74(8):1768–1775. <http://onlinelibrary.wiley.com/doi/10.2193/2009-127/abstract> (Accessed August 2015).
- Hobbs, J. 2004. Spotted Owl nest site descriptions (2002 and 2003) and telemetry and monitoring of juvenile Spotted Owls (2003 and 2004) (*Strix occidentalis caurina*) in British Columbia. [Unpublished report]. Ministry of Water, Land and Air Protection, Victoria, B.C.
- _____. 2005. Spotted Owl inventory and nest site descriptions (2004) and telemetry and monitoring of juvenile Spotted Owls (2004 and 2005) in British Columbia. [Unpublished report]. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, B.C. https://www.for.gov.bc.ca/dcs/sustainable_forestry/lillooet/2004_Sp_Owl_Surveys_fnl_rprt.pdf (Accessed August 2015).
- Horn, H.L., P. Arcese, K. Brunt, A.E. Burger, H. Davis, F. Doyle, K. Dunsworth, P. Friele, S. Gordon, A.N. Hamilton, S.L. Hazlitt, S. Leigh-Spencer, G. MacHutchon, T. Mahon, E. McClaren, V. Michelfelder, B. Pollard, S. Taylor, & F.L. Waterhouse. 2009a. Part 1: Assessment of co-location outcomes and implications for focal species management under EBM. EBM Working Group Focal Species Project, Integrated Land Management Bureau, Nanaimo, B.C. Report No. 1. https://www.for.gov.bc.ca/tasb/slrp/lrmp/nanaimo/cenocast/ebmwg_docs/e102c_report_1.pdf (Accessed August 2015).
- Horn, H.L., P. Arcese, K. Brunt, A. Burger, H. Davis, F. Doyle, K. Dunsworth, P. Friele, S. Gordon, T. Hamilton, G. MacHutchon, T. Mahon, E. McClaren, V. Michelfelder, B. Pollard, G. Sutherland, S. Taylor, & L. Waterhouse. 2009b. Part 3: Knowledge base for focal species and their habitats in coastal B.C. EBM Working Group Focal Species Project, Integrated Land Management Bureau, Nanaimo, B.C. Report No. 3. https://www.for.gov.bc.ca/tasb/slrp/lrmp/nanaimo/cenocast/ebmwg_docs/ei02c_report_3.pdf (Accessed August 2015).
- Iverson, G.C., G.D. Hayward, K. Titus, E. DeGayner, R.E. Lowell, D.C. Crocker-Bedford, P.F. Schempff, & J. Lindell. 1996. Conservation assessment for the Northern Goshawk in southeast Alaska. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, OR. General Technical Report PNW-GTR-387. <http://www.fs.fed.us/pnw/pubs/goshawk.pdf> (Accessed August 2015).
- Jewett, S.G., W.P. Taylor, W.T. Shaw, & J.W. Aldrich. 1953. *Birds of Washington State*. University of Washington Press, Seattle, WA.
- Jiménez-Franco, M.V., J.E. Martínez, & J.F. Calvo. 2011. Territory occupancy dynamics in a forest raptor community. *Oecologia* 166:507–516.
- Johnson, D.R. 1989. Body size of Northern Goshawks on coastal islands of British Columbia. *Wilson Bulletin* 101(4):637–639. <http://www.jstor.org/stable/4162794> (Accessed August 2015).
- _____. 1992. Spotted Owls, Great Horned Owls, and forest fragmentation in the central Oregon Cascades. MSc thesis. Oregon State University, Corvallis, OR.
- Keane, J. 1999. Ecology of the Northern Goshawk in the Sierra Nevada, California. PhD dissertation. University of California, Davis, CA.
- Keane, J.J., M.L. Morrison, & D.M. Fry. 2006. Prey and weather factors associated with temporal variation in Northern Goshawk reproduction in the Sierra Nevada, CA. *Studies in Avian Biology* 31:85–99.
- Kennedy, P.L. 1997. The Northern Goshawk (*Accipiter gentilis atricapillus*): is there evidence of a population decline? *Journal of Raptor Research* 31(2):95–106.
- _____. 2003. Northern Goshawk (*Accipiter gentilis atricapillus*): a technical conservation assessment. U.S. Department of Agriculture Forest Service, Rocky Mountain Region, Fort Collins, Colo. Species Conservation Project. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5182005.pdf (Accessed August 2015).
- Kennedy, P.L., & D.W. Stahlecker. 1993. Responsiveness of nesting Northern Goshawks to taped broadcasts of 3 conspecific calls. *Journal of Wildlife Management* 57:249–257.
- Kennedy, P.L., & J.M. Ward. 2003. Effects of experimental food supplementation on movements of juvenile Northern Goshawk (*Accipiter gentilis atricapillus*). *Oecologia* 134(2):284–291. <http://link.springer.com/article/10.1007%2Fs00442-002-1108-0> (Accessed August 2015).
- Kennedy, P.L., J.M. Ward, G.A. Rinker, & J.A. Gessaman. 1994. Post-fledging areas in Northern Goshawk home ranges. *Studies in Avian Biology* 16:75–82.
- Kenward, R.E. 1982. Goshawk hunting behaviour, and range size as a function of food and habitat availability. *Journal of Animal Ecology* 51(1):69–80. <http://www.jstor.org/stable/4311> (Accessed August 2015).

- _____. 2006. Death and demography. In: The goshawk. T. & A.D. Poyser Ltd., London, UK. pp. 217–251.
- Kenward, R.E., V. Marcström, & M. Karlbom. 1999. Demographic estimates for radio-tagged models of age specific survival and breeding in goshawks. *Journal of Animal Ecology* 68(5):1020–1033. <http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2656.1999.00347.x/full> (Accessed August 2015).
- Kernohan, B.J., R.A. Gitzen, & J.J. Millspaugh. 2001. Analysis of animal space use and movements. In: Radio tracking animal populations. J.J. Millspaugh, & J.M. Marzluff (editors). Academic Press, San Diego, CA. pp. 125–166.
- Kostrzewa, A. 1996. A comparative study of nest-site occupancy and breeding performance as indicators for nesting-habitat quality in three European raptor species. *Ethology, Ecology and Evolution* 8(1):1–18. <http://www.tandfonline.com/doi/abs/10.1080/08927014.1996.9522931> (Accessed August 2015).
- Kostrzewa, A., & R. Kostrzewa. 1990. The relationship of spring and summer weather with density and breeding performance of the buzzard *Buteo buteo*, goshawk *Accipiter gentilis* and kestrel *Falco tinnunculus*. *Ibis* 132:550–559.
- Krüger, O. 2002. Interactions between Common Buzzard *Buteo buteo* and goshawk *Accipiter gentilis*: trade-offs revealed by a field experiment. *Oikos* 96(3):441–452. <http://onlinelibrary.wiley.com/doi/10.1034/j.1600-0706.2002.960306.x/abstract> (August 2015).
- _____. 2005. Age at first breeding and fitness in goshawk *Accipiter gentilis*. *Journal of Animal Ecology* 74(2):266–273. <http://www.jstor.org/stable/3505615> (Accessed August 2015).
- Krüger, O., & J. Lindström. 2001. Habitat heterogeneity affects population growth in goshawk *Accipiter gentilis*. *Journal of Animal Ecology* 70(2):173–181. <http://www.jstor.org/stable/2693416> (Accessed August 2015).
- La Sorte, F.A., R.W. Mannan, R.T. Reynolds, & T.G. Grubb. 2004. Habitat associations of sympatric Red-tailed Hawks and Northern Goshawks on the Kaibab Plateau. *Journal of Wildlife Management* 68(2):307–317.
- Lewis, S.B., & C.J. Flatten. 2004. Analysis of Queen Charlotte Goshawk radio-telemetry and prey-habitat data in conjunction with the USDA Forest Service Alaska Department of Fish and Game. [Unpublished report].
- Lewis, S.B., K. Titus, Fuller, M.R. (2006). Northern Goshawk diet during the nesting season in southeast Alaska. *Journal of Wildlife Management*, 70(4), 1151–1160.
- Lilieholt, R.J., W.B. Kessler, & K. Merrill. 1993. Stand index applied to timber and goshawk habitat objectives in Douglas-fir. *Environmental Management* 17(6):773–779. <http://link.springer.com/article/10.1007%2FBF02393898> (Accessed August 2015).
- Lindén, H., & M. Wikman. 1983. Goshawk predation on tetraonids: availability of prey and diet of the predator in the breeding season. *Journal of Animal Ecology* 52:953–968.
- Mahon, T. 2008. Effects of forest development near nest sites on the reproductive success of Northern Goshawks (*Accipiter gentilis*): an adaptive management approach. [Unpublished report]. Bulkley Valley Centre for Natural Resources Research and Management, Smithers, B.C.
- _____. 2009. Northern Goshawks in west-central British Columbia: 10-year project summary. Bulkley Valley Centre for Natural Resources Research and Management, Smithers, B.C. [Unpublished report]. http://bvcentre.ca/files/research_reports/08-07NadinaGoshawkTechReport.pdf (Accessed August 2015).
- Mahon, T., & F.I. Doyle. 2005. Effects of timber harvesting near nest sites on the reproductive success of Northern Goshawks (*Accipiter gentilis*). *Journal of Raptor Research* 39(3):335–341.
- Mahon, T., E.L. McClaren, & F.I. Doyle. 2008. Northern Goshawk (*Accipiter gentilis laingi*) habitat models for coastal British Columbia. Nesting and foraging habitat suitability models and territory analysis model. [Unpublished report]. Northern Goshawk *Accipiter gentilis laingi* Recovery Team, Habitat Recovery Implementation Group, Nanaimo, B.C.
- _____. 2015. Northern Goshawk (*Accipiter gentilis laingi*) habitat models for coastal British Columbia. Nesting and foraging habitat suitability models and territory analysis model. [Unpublished report]. Northern Goshawk *Accipiter gentilis laingi* Recovery Team, Habitat Recovery Implementation Group, Nanaimo, B.C.
- Malt, J.M., & D.B. Lank. 2009. Marbled Murrelet nest predation risk in managed forest landscapes: dynamic fragmentation effects at multiple scales. *Ecological Applications* 19(5):1274–1287.
- Manning, E.T., P. Chytyk, & J.M. Cooper. 2002. Queen Charlotte Goshawk species-habitat model for Canfor TFL 37, Woss, B.C. Canadian Forest Products Ltd., Woss, B.C. [Unpublished report].
- Manning, E.T., P. Chytyk, & M.G. Shepard. 2012. Western Forest Products Northern Goshawk nest territory monitoring 2012 – Vancouver Island. [Unpublished report]. Strategic Resource Solutions, Victoria, B.C.

- Manning, Cooper, & Associates. 2004. Silviculture guidelines and practices for maintaining or recruiting key habitat objectives. B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, B.C. http://www.env.gov.bc.ca/fia/documents/mca_silvbmp.pdf (Accessed August 2015).
- Manning, E.T., & I.A. Manley. 2014. Results of fungal inoculation treatments as a habitat enhancement tool in the East Kootenay region of British Columbia: 2007–2013. B.C. Ministry of Forests, Lands and Natural Resource Operations, Victoria, B.C. Extension Note No. 112. <https://www.for.gov.bc.ca/hfd/pubs/Docs/En/EN112.pdf> (Accessed August 2015).
- Marcström, V., & R. Kenward. 1981. Sexual and seasonal variation in condition and survival of Swedish goshawks *Accipiter gentilis*. *Ibis* 123:311–327.
- McClaren, E.L. 2001. Factors influencing goshawk detectability and reproduction on Vancouver Island, British Columbia. MSc thesis. Colorado State University, Fort Collins, CO.
- _____. 2004. Queen Charlotte Goshawk *Accipiter gentilis laingi*. In: Accounts and Measures for Managing Identified Wildlife – Version 2004. B.C. Ministry of Water, Land and Air Protection, Victoria, B.C. http://www.env.gov.bc.ca/wld/frpa/iwms/documents/Birds/b_queencharlottegoshawk.pdf (Accessed August 2015).
- _____. 2005. Northern Goshawk (*Accipiter gentilis laingi*) population inventory summary for Vancouver Island, British Columbia 1994–2002. B.C. Ministry of Environment, Victoria B.C. Wildlife Bulletin No. B-117.
- McClaren, E.L., P.L. Kennedy, & P.L. Chapman. 2003. Efficacy of male goshawk food-delivery calls in broadcast surveys on Vancouver Island. *Journal of Raptor Research* 37(3):198–208.
- McClaren, E.L., P.L. Kennedy, & S.R. Dewey. 2002. Do some Northern Goshawk nest areas consistently fledge more young than others? *Condor* 104(2):343–352.
- McClaren, E.L., P.L. Kennedy, & D.D. Doyle. 2005. Northern Goshawk (*Accipiter gentilis laingi*) post-fledging areas on Vancouver Island, British Columbia. *Journal of Raptor Research* 39(3):253–263.
- McClaren, E.L., & C.L. Pendergast. 2003. Relationship between forest age class distribution around Northern Goshawk nests and occupancy and nest productivity patterns at three spatial scales. [Unpublished report]. B.C. Ministry of Water, Land and Air Protection, Nanaimo, B.C.
- McGrath, M.T., S. DeStefano, R.A. Riggs, L.L. Irwin, & G.L. Roloff. 2003. Spatially explicit influences on Northern Goshawk nesting habitat in the Interior Pacific Northwest. *Wildlife Monographs* No. 154. <http://www.jstor.org/stable/3830854> (Accessed August 2015).
- McLaughlin, R.T. 2002. Northern Goshawk nest monitoring on Br 128, Sproat Lake Timberlands. [Unpublished report]. Nanaimo Woodlands, B.C. Coastal Group, Nanaimo, B.C.
- Mills, T.J., T.M. Quigley, & F.J. Everest. 2001. Science-based natural resource management decisions: What are they? *Renewable Resources Journal* 19:10–15. http://www.fs.fed.us/pnw/pubs/journals/pnw_2001_mills001.pdf (Accessed August 2015).
- Mitchell, A., V. Michelfelder, & R. van der Marel. 2008. Proposed wildlife habitat areas for the Northern Goshawk (*Accipiter gentilis laingi*) on the Central Coast of British Columbia. [Unpublished report]. B.C. Ministry of Environment, Hagensborg, B.C. https://www.for.gov.bc.ca/tasb/slrp/lrmp/nanaimo/cencoast/ebmwg_docs/e102a_NOGO_general_release_report_CC.pdf (Accessed August 2015).
- Morrison, J.L., M. Terry, & P.L. Kennedy. 2006. Potential factors influencing nest defense in diurnal North American raptors. *Journal of Raptor Research* 40:98–110.
- Morrison, M.L., R.J. Young, J.S. Romsos, & R. Golightly. 2011. Restoring forest raptors: Influence of human disturbance and forest condition on Northern Goshawks. *Restoration Ecology* 19(2): 273–279.
- Moser, B.W., & E.O. Garton. 2009. Short-term effects of timber harvest and weather on Northern Goshawk reproduction in northern Idaho. *Journal of Raptor Research* 43(1):1–10.
- Nagorsen, D. 2002. An identification manual to the small mammals of British Columbia. B.C. Ministry of Sustainable Resource Management, B.C. Ministry of Water, Land and Air Protection, and Royal B.C. Museum, Victoria, B.C. http://www.env.gov.bc.ca/wld/idkey_intropg.htm (Accessed August 2015).
- Negrave, R., & D. Stewart. 2010. Silviculture practices for enhancing old forest stand structure in red- and blue-listed plant communities in the CDFmm: Interim Document. Version 2.0. Coastal Douglas fir and Associated Ecosystems Conservation Partnership, Nanaimo, B.C. <http://www.cdfcp.ca/attachments/CDFmm%20Silviculture%20Practices%20BMP.pdf> (Accessed October 2015).
- Newton, I. 1979. Population ecology of raptors. T. & A.D. Poyser, Berkhamsted, UK.
- _____. 1998. Population limitation in birds. Academic Press, San Diego, CA. pp. 288–291.
- Newton, I., M. Marquiss, & A. Village. 1983. Weights, breeding, and survival in European Sparrowhawks. *Auk* 100:344–354.
- Nielsen, J.T., & J. Drachmann. 2003. Age-dependent reproductive performance in Northern Goshawks *Accipiter gentilis*. *Ibis* 145:1–8.

- Northern Goshawk *Accipiter gentilis laingi* Recovery Team. 2008. Recovery strategy for the Northern Goshawk, laingi subspecies (*Accipiter gentilis laingi*) in British Columbia. B.C. Ministry of Environment, Victoria, B.C. http://www.env.gov.bc.ca/wld/documents/recovery/rcvrystrat/northern_goshawk_rcvry_strat_200508.pdf (Accessed August 2015).
- Olsen, P.D., & J. Olsen. 1989. Breeding of the Peregrine Falcon *Falco peregrinus*: I. Weather, nest spacing and territory occupancy. *Emu* 88(4):195–201.
- Orians, G.H., & N.E. Pearson. 1979. On the theory of central place foraging. In: Analysis of ecological systems. D.J. Horn, R.D. Mitchell, & G.R. Stairs (editors). Ohio State University Press. Columbus, Ohio. Ohio State University Press, Columbus, OH. pp. 155–177.
- Parks Canada. 2014. Recovery Strategy for the Northern Goshawk *laingi* subspecies (*Accipiter gentilis laingi*) in Canada. Ottawa, ON. *Species at Risk Act* Recovery Strategy Series. [Unpublished draft].
- Patla, S.M. 1997. Nesting ecology and habitat of the Northern Goshawk in undisturbed and timber harvest areas on the Targhee National Forest, greater Yellowstone ecosystem. MSc thesis. Idaho State University, Boise, ID.
- _____. 2005. Monitoring results of Northern Goshawk nesting areas in the Greater Yellowstone ecosystem: Is decline in occupancy related to habitat change? *Journal of Raptor Research* 39(3):321–334.
- Pelletier, M. 2000. The effect of Red Squirrel (*Tamiasciurus hudsonicus*) abundance on the productivity and territory occupancy of Queen Charlotte Goshawks (*Accipiter gentilis laingi*). [Unpublished Biology Cooperative Education report]. University of Victoria, Victoria, B.C.
- Penteriani, V. 1997. Long-term study of a goshawk breeding population on a Mediterranean mountain (Abruzzi Apennines, Central Italy): density, breeding performance and diet. *Journal of Raptor Research* 31:308–312.
- _____. 2002. Goshawk nesting habitat in Europe and North America: A review. *Ornis Fennica* 79(4):149–163. http://www.vincenzopenteriani.org/publications_pdfs/accipiter_gentilis_ornis_fennica1.pdf (Accessed August 2015).
- Penteriani, V., & B. Faivre. 2001. Effects of harvesting timber stands on goshawk nesting in two European areas. *Biological Conservation* 101(2):211–216. <http://www.sciencedirect.com/science/article/pii/S0006320701000684> (Accessed August 2015).
- Pojar, J.E., K. Klinka, & D.A. Demarchi. 1991. Coastal Western Hemlock biogeoclimatic zone. In: Ecosystems of British Columbia. D.V. Meidinger & J.E. Pojar (editors). B.C. Ministry of Forests, Research Branch, Victoria, B.C. Special Report Series No. 6. pp. 95–112. <https://www.for.gov.bc.ca/hfd/pubs/docs/Srs/Srs06/chap6.pdf> (Accessed August 2015).
- Province of British Columbia. 2004. Identified wildlife management strategy. B.C. Ministry of Environment, Victoria, B.C. <http://www.env.gov.bc.ca/wld/frpa/iwms/index.html> (Accessed August 2015).
- _____. 2013. Guidelines for raptor conservation during urban and rural land development in British Columbia – A companion document to develop with care 2012. Nanaimo, B.C. http://www.env.gov.bc.ca/wld/documents/bmp/raptor_conservation_guidelines_2013.pdf (Accessed August 2015).
- Province of British Columbia & the Council of Haida Nation. 2007. Haida Gwaii strategic land use agreement. Victoria, B.C. http://www.haidanation.ca/Pages/Agreements/pdfs/Haida_Gwaii_Strategic_Land_Use_Agreement.pdf (Accessed August 2015).
- Pyke, G.H., H.R. Pulliam, & E.L. Charnov. 1977. Optimal foraging theory: a selective review of theory and tests. *Quarterly Review of Biology* 52(2):137–154. <http://www.jstor.org/stable/2824020> (Accessed August 2015).
- Reich, R.M., S.M. Joy, & R.T. Reynolds. 2004. Predicting the location of Northern Goshawk nests: modeling the spatial dependency between nest locations and forest structure. *Ecological Modelling* 176(1–2):109–133. <http://www.sciencedirect.com/science/article/pii/S030438000300560X> (Accessed August 2015).
- Reynolds, R.T., R.T. Graham, & D.A. Boyce. 2008. Northern Goshawk habitat: an intersection of science, management, and conservation. *Journal of Wildlife Management* 72(4):1047–1055. <http://onlinelibrary.wiley.com/doi/10.2193/2007-131/abstract> (Accessed August 2015).
- Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce Jr., G. Goodwin, R. Smith, & E.L. Fisher. 1992. Management recommendations for Northern Goshawk in the southwestern United States. U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. General Technical Report RM-217. http://www.fs.fed.us/rm/pubs_rm/rm_gtr217.pdf (Accessed August 2015).

- Reynolds, R.T., & S.M. Joy. 1998. Distribution, territory occupancy, dispersal, and demography of Northern Goshawks on the Kaibab Plateau, AZ. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station, Fort Collins, CO. Arizona Game and Fish Heritage Project No. 194045. http://www.fs.fed.us/rm/pubs_other/rmrs_1998_reynolds_r001.pdf (Accessed August 2015).
- _____. 2006. Demography of Northern Goshawks in Northern Arizona 1991–1996. *Studies in Avian Biology* 31:63–74.
- Reynolds, R.T., S.M. Joy, & D.G. Leslie. 1994. Nest productivity, fidelity, and spacing of Northern Goshawks in northern Arizona. *Studies in Avian Biology* 16:106–113.
- Reynolds, R.T., J.D. Wiens, S.M. Joy, & S.R. Salafsky. 2005. Sampling considerations for demographic and habitat studies of Northern Goshawks. *Journal of Raptor Research* 39:274–285.
- Reynolds, R.T., J.D. Wiens, & S.R. Salafsky. 2006. A review and evaluation of factors limiting Northern Goshawk populations. *Studies in Avian Biology* 31:260–273.
- Roberts, A-M. 1997. Food habitats of Northern Goshawks in the Queen Charlotte Islands and in the Kispiox Forest District 1996. [Unpublished report]. Smithers, B.C.
- Ruddock, M., & D.P. Whitfield. 2007. Goshawk *Accipiter gentilis*. In: A review of disturbance in selected bird species. M. Ruddock & D.P. Whitfield (editors). A report from Natural Research (Projects) Ltd. to Scottish Natural Heritage. pp. 99–104. <http://www.snh.org.uk/pdfs/strategy/renewables/BIRDSD.pdf> (Accessed August 2015).
- Rutz, C., R.G. Bijlsma, M. Marquiss, & R.E. Kenward. 2006. Population limitation in the Northern Goshawk in Europe: a review with case studies. In: The Northern Goshawk: a technical assessment of its status, ecology and management. M.L. Morrison (ed.), Cooper Ornithological Society. *Studies in Avian Biology* 31:158–197.
- Salafsky, S.R., R.T. Reynolds, B.R. Noon, & J.A. Wiens. 2007. Reproductive responses of Northern Goshawks to variable prey populations. *Journal of Wildlife Management* 71(7):2274–2283.
- Sánchez-Zapata, J.A., & J.F. Calvo. 1999. Raptor distribution in relation to landscape composition in semi-arid Mediterranean habitats. *Journal of Applied Ecology* 36(2):254–262.
- Santangeli, A., H. Lehtoranta, & T. Laaksonen. 2012. Successful voluntary conservation of raptor nests under intensive forestry pressure in a boreal landscape. *Animal Conservation* 15(6):571–578. <http://onlinelibrary.wiley.com/doi/10.1111/j.1469-1795.2012.00551.x/abstract> (Accessed August 2015).
- Schoener, T.W. 1971. Theory of feeding strategies. *Annual Review of Ecology and Systematics* 2:369–404. <http://www.jstor.org/stable/2096934> (Accessed August 2015).
- Smith, J.R. 2012. Northern Goshawk habitat and territory modeling results. [Unpublished report]. Unpublished model outputs prepared for the B.C. Ministry of Forests, Lands and Natural Resource Operations, Victoria, B.C.
- _____. 2013. Northern Goshawk habitat and territory modeling results. [Unpublished report]. Unpublished model outputs prepared for Parks Canada, Vancouver, B.C.
- Smith, J.R., & G. Sutherland. 2008. Northern Goshawk (*Accipiter gentilis laingi*) habitat and territory models: modelling methodology and implementation and scenario results for coastal British Columbia. The Northern Goshawk Habitat Recovery Implementation Group. [Unpublished report]. http://www.for.gov.bc.ca/hfd/library/FIA/2006/LBIPI_6443004a.pdf (Accessed August 2015).
- Sonsthagen, S.A., E.L. McClaren, F.I. Doyle, K. Titus, G.K. Sage, R.E. Wilson, J. Gust, & S.L. Talbot. 2012. Identification of metapopulation dynamics among Northern Goshawks of the Alexander Archipelago, Alaska, and coastal British Columbia. *Conservation Genetics* 13:1045–1057. <http://link.springer.com/article/10.1007%2Fs10592-012-0352-z> (Accessed August 2015).
- Speiser, R. 1992. Notes on the natural history of the Northern Goshawk. *Kingbird* 42:133–137.
- Speiser, R., & T. Bosakowski. 1988. Nest site preferences of Red-tailed Hawks in the highlands of southeastern New York and northern New Jersey. *Journal of Field Ornithology* 59:361–368.
- Squires, J.R., & P.L. Kennedy. 2006. Northern Goshawk ecology: an assessment of current knowledge and information needs for conservation and management. In: The Northern Goshawk: a technical assessment of its status, ecology and management. M.L. Morrison (ed.), Cooper Ornithological Society. *Studies in Avian Biology* 31:8–62.
- Squires, J.R., & R.T. Reynolds. 1997. Northern Goshawk (*Accipiter gentilis*). In: Birds of North America, No. 298. A. Poole & F. Gill (editors). The Academy of Natural Sciences, Philadelphia, Penn. and Am. Ornithologists' Union, Washington, DC.
- Stathers, R.J., T.P. Rollerson, & S.J. Mitchell. 1994. Windthrow handbook for British Columbia forests. B.C. Ministry of Forests, Victoria, B.C. Research Program Working Paper 9401. <https://www.for.gov.bc.ca/hfd/pubs/docs/wp/wp01.pdf> (Accessed August 2015).

- Stephens, R.M. 2001. Migration, habitat use, and diet of Northern Goshawks that winter in the Uinta Mountains, Utah. MSc thesis. University of Wyoming, Laramie, WY.
- Stuart-Smith, A.K., W.L. Harrower, T. Mahon, E.L. McClaren, & F.I. Doyle. 2012. A scientific basis for managing Northern Goshawk breeding areas in the interior of British Columbia: best management practices. FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. FORREX Series 29. http://www.forrex.org/sites/default/files/forrex_series/176-goshawk-final.pdf (Accessed August 2015).
- Sunde, P. 2002. Starvation mortality and body condition of goshawks *Accipiter gentilis* along a latitudinal gradient in Norway. *Ibis* 144:301–310.
- Talbot, S.L., S.A. Sonsthagen, & G.K. Sage. 2011. Genetic relationship among goshawks of British Columbia and Alaska. [Unpublished report]. U.S. Geological Survey, Alaska Science Center, Anchorage, AK.
- Tapia, L., P.L. Kennedy, & R. William-Mannan. 2007. Habitat sampling. In: Raptor research and management techniques. D. Bird & K.L. Bildstein (editors). Hancock House Publishers, Surrey, B.C. pp. 153–170. http://raptors.hancockwildlife.org/filemgmt_data/files/Raptor_Research_all.pdf (Accessed August 2015).
- Taverner, P.A. 1940. Variation in the American Goshawk. *Condor* 42:157–160.
- Taylor, A.R., & R.L. Knight. 2003. Behavioral responses of wildlife to human activity: terminology and methods. *Wildlife Society Bulletin* 31(4):1263–1271. <http://www.jstor.org/stable/3784477> (Accessed August 2015).
- TimberWest and Island Timberlands. 2012. Private managed forest land goshawk habitat management: an approach by two landowners. [Unpublished report].
- Titus, K., C.J. Flatten, & R.E. Lowell. 1994. Northern Goshawk ecology and habitat relationships on the Tongass National Forest: goshawk nest sites, food habits, morphology, home range and habitat data. [Annual progress report]. U.S. Department of Agriculture, Forest Service, Alaska Region; Alaska Department of Fish and Game, Division of Wildlife Conservation, Southeast Regional Office, Douglas, AK.
- Titus, K., C. Flatten, & R. Lowell. (1999). Goshawk ecology and habitat relationships on the Tongass National Forest. [1998 annual report]. Study SE-4-2. Ketchikan, AK.
- Titus, K., & S.B. Lewis. 2000. Northern Goshawk monitoring, population ecology and diet on the Tongass National Forest. Alaska Department of Fish and Game. Annual Research Performance Report. Federal Aid Study SE-4-2-5. pp. 1–79. http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/federal_aid/goshawk.pdf (Accessed August 2015).
- Titus, K., S. Lewis, W. Smith, R. Fairbanks, R. Lowell, M. Goldstein, G. Pendleton, G. Fisher, & M. Cady. 2006. Conservation strategy review: an assessment of new information since 1997. Northern Goshawks on the Tongass National Forest: summary of study findings related to forest management. Interagency review of Tongass National Forest conservation strategy.
- Toews, M., & W. Wall. 2012. Summary of Northern Goshawk territory monitoring 2012. [Unpublished report]. Prepared for TimberWest Ltd., Duncan, B.C.
- Topp, C.M., & K. Winker. 2008. Genetic patterns of differentiation among five species of landbirds on the Queen Charlotte Islands, British Columbia. *Auk* 125(2):461–472. <http://www.bioone.org/doi/abs/10.1642/AUK-13-187.1> (Accessed August 2015).
- Tornberg, R., & A. Colpaert. 2001. Survival, ranging, habitat choice and diet of the Northern Goshawk *Accipiter gentilis* during winter in Northern Finland. *Ibis* 143(1):41–50. <http://onlinelibrary.wiley.com/doi/10.1111/j.1474-919X.2001.tb04168.x/abstract> (Accessed August 2015).
- Toyne, E.P. 1997. Nesting chronology of Northern Goshawks (*Accipiter gentilis*) in Wales: implications for forest management. *Forestry* 70(2):121–127. <http://forestry.oxfordjournals.org/content/70/2/121.full.pdf+html> (Accessed August 2015).
- Tripp, R., & R. Coombs. 2009. Queen Charlotte Goshawk (*Accipiter gentilis laingi*) Vancouver Island nest inventory, 2009. [Unpublished report]. TimberWest, Nanaimo, B.C.
- U.S. Department of Agriculture Forest Service. 1997. Tongass National Forest land and resource management plan. Forest Service, Ketchikan, AK. R10-MB 338. <http://www.fs.usda.gov/detail/tongass/landmanagement/planning/?cid=stelprdb5445359> (Accessed August 2015).
- _____. 2008. Tongass National Forest land and resource management plan. Ketchikan, AK. R10-MB-603b. https://fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5367422.pdf (Accessed August 2015).
- U.S. Fish and Wildlife Service. 2007. Queen Charlotte Goshawk status review. U.S. Fish and Wildlife Service, Alaska Region, Juneau Fish and Wildlife Field Office, Juneau, AK. http://www.fws.gov/alaska/fisheries/endangered/pdf/goshawk_status_review.pdf (Accessed August 2015).

- Utzig, G. 2011. Climate change projections for the West Kootenays. http://www.kootenayresilience.org/CC-WK_scenarios_2-22-11.pdf (Accessed August 2015).
- Ward, J.M., & P.L. Kennedy. 1996. Effects of supplemental food on size and survival of juvenile Northern Goshawks. *Auk* 113:200–208.
- Ward, L.Z., D.K. Ward, & T.J. Tibbits. 1992. Canopy density analysis at goshawk nesting territories on the North Kaibab Ranger District, Kaibab National Forest. Arizona Game and Fish Department, Nongame and Endangered Wildlife Program, Phoenix, AZ. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_021353.pdf (Accessed August 2015).
- Warner, B., R. Mathewes, & J. Clague. 1982. Ice-free conditions on the Queen Charlotte Islands, British Columbia, at the height of the late Wisconsin glaciation. *Science* 218(4573):675–677. <http://www.sciencemag.org/content/218/4573/675.short> (Accessed August 2015).
- Watson, J.W., D.W. Hays, & S.P. Finn. 1998. Prey of breeding Northern Goshawks in Washington. *Journal of Raptor Research* 32:297–305.
- Webster, J.D. 1988. Some bird specimens from Sitka, Alaska. *Murrelet* 69(2):46–48. <http://www.jstor.org/stable/3535845> (Accessed August 2015).
- Whaley, W.H., & C.M. White. 1994. Trends in geographic variation of Cooper's hawk and northern goshawk in North America: a multivariate analysis. *Western Foundation of Vertebrate Zoology* 5(3):161–209.
- Wiens, D.J., R.T. Reynolds, & B.R. Noon. 2006b. Juvenile movement and natal dispersal of Northern Goshawks in Arizona. *Condor* 108:253–269.
- Wiens, J.D., B.R. Noon, & R.T. Reynolds. 2006a. Post-fledging survival of Northern Goshawks: the importance of prey abundance, weather, and dispersal. *Ecological Applications* 16(1):406–418. <http://www.esajournals.org/doi/abs/10.1890/04-1915> (Accessed August 2015).
- Wiens, J.D., & R.T. Reynolds. 2005. Is fledging success a reliable index of fitness in Northern Goshawks? *Journal of Raptor Research* 39(3):210–221.
- Wilson, S.F. 2012. Management protocol for goshawk nests discovered on BCTS Operating areas. Version 1.0. [Unpublished report]. BC Timber Sales, Strait of Georgia, Campbell River, B.C.
- Woodbridge, B., & P.J. Detrich. 1994. Territory occupancy and habitat patch size of Northern Goshawks in the southern Cascades of California. *Studies in Avian Biology* 16:83–87.
- Younk, J.V., & M.J. Bechard. 1994. Breeding ecology of the Northern Goshawk in high-elevation aspen forests of northern Nevada. *Studies in Avian Biology* 16:119–121.
- Zeeman, A. 2003. Dawn vocalization surveys for Northern Goshawks (*Accipiter gentilis laingi*) on Vancouver Island during the 1999 and 2000 courtship periods. [Unpublished report]. B.C. Ministry of Water, Land and Air Protection and the British Columbia Conservation Foundation, Victoria, B.C.

Active nest: a nest where there is sufficient evidence that a breeding attempt has occurred within a given year. Sufficient evidence includes eggshell fragments at the base of a nest tree, an incubating adult or nestlings on a nest, or evidence that nestlings were present within a nest such as the presence of excrement below the nest tree.

Alternative nest: other nests (besides the active one) within a goshawk pair's breeding area. Goshawks typically build several nests within breeding areas.

Annual home range: area that includes the annual movements of a breeding pair of goshawks, within a territory, during all seasons (see Table 2).

Apparently secure: B.C. Conservation Data Centre definition meaning uncommon but not rare; some cause for long-term concern because of population declines or other factors.

Best management practices: approaches based on science that, if followed, should allow qualified environmental professionals to meet the required standard(s) or achieve the desired objective(s). Best management practice and guideline documents exist to help qualified environmental professionals act as environmental stewards.

Biogeoclimatic subzone: a climatic or zonal classification system that uses vegetation, soils, and topography to infer the regional climate of a geographic area. Biogeoclimatic subzones are delineated where different plant associations occur; this is the basic unit of this climatic classification system. Appendix 2 contains a key to biogeoclimatic subzone abbreviations.

Biogeoclimatic variant: areas that are slightly drier, wetter, snowier, warmer, or colder than that considered typical for the subzone. These climatic differences result in corresponding differences in vegetation, soil, and ecosystem productivity, although the changes in the vegetation are not sufficient to define a new plant association. The differences in vegetation are evident as a distinct climax plant sub-association.

Biogeoclimatic zone: a large geographic area with a broadly homogeneous macroclimate. A zone has characteristic webs of energy flow and nutrient cycling and typical patterns of vegetation and soils. We characterize zones as having a distinct zonal plant order; that is, the vegetation classification groups zonal plant associations in the category of plant order. Zones also have characteristic, prevailing soil-forming processes and one or more typical, major climax species of tree, shrub, herb, and (or) moss. Appendix 2 contains a key to biogeoclimatic zone abbreviations.

Breeding area: this is the primary ecological unit for all goshawk breeding activities including courtship, nesting, fledging, and movements of fledglings before dispersal. This area includes nest trees (current and potential future ones), plucking posts, roosts, and post-fledging areas associated with each nest tree over multiple years (see Table 2).

Breeding home range: the area used by a pair of goshawks during the breeding season, encompassing both the breeding areas and foraging areas (see Table 2).

Broadcast surveys: a method of surveying or inventorying for species that involves playing recorded vocalizations or calls using a speaker device. Broadcast calls are used to mimic the target species in hopes of eliciting a response so that surveyors can increase their ability to detect species (often elusive species).

Category of species at risk: the Minister responsible for the *Wildlife Act* may establish a category of species at risk under section 13(1) of the Government Actions Regulation (B.C. Reg. 582/2004) of the *Forest and Range Practices Act*.²⁴ This category of species at risk represents those species that may be affected by forest or range management on Crown land and are listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Central-place forager: this term was introduced by Orians and Pearson (1979) to describe situations in which a forager must bring the items it captures to a given location, which is often centrally located within its territory. This concept takes into consideration energy budgets associated with foraging related to distance foragers must travel from a central place (i.e., nest) (energetic outputs) relative to size of prey captured (energetic inputs).

Coastal goshawk: common term in this report used to reference Northern Goshawk subspecies *Accipiter gentilis laingi* that occurs within coastal British Columbia, southeast Alaska, and western Washington forests (see Figure 1).

Core-use area: area of an organism's larger home range where activities (such as breeding) are concentrated.

Critical habitat (under the *Species at Risk Act*): is vital to the survival or recovery of wildlife species. The habitat may be an identified breeding site, nursery area, or feeding ground. For species at risk, these habitats are of crucial importance and must be identified and included in recovery strategies or action plans.

Culmen: the upper ridge of a bird's bill.

Dawn vocalization surveys: a goshawk-detection technique that relies on listening to dawn and morning vocalizations occurring between adult male and female goshawks, especially during the courtship phase.

Designatable unit: is a term used by COSEWIC to define taxonomic entities below the species level, such as subspecies, varieties, or geographically or genetically distinct populations. This recognizes that conservation of biological diversity requires protection for taxonomic entities below the species level (i.e., designatable units) and gives COSEWIC a mandate to assess these entities when warranted.

Featured species: a term, highlighted in Alaska's Wildlife Action Plan (Alaska Department of Fish and Game 2006), that refers to a large number of species, species groups, and (or) species assemblages, and the habitats supporting them.

Foraging area: the portion of home ranges where goshawks pursue and capture prey.

General wildlife measures: the management prescriptions that must be followed within Wildlife Habitat Areas.

Guidelines: a set of recommended or suggested methods or actions that should be followed in most circumstances to assist administrative and planning decisions, and their implementation in the field. Guidelines may consist of policy statements, procedures, or checklists. They are provided as a broad framework of recommended actions to be taken and, therefore, provide some flexibility for decision making. Note that guidelines cannot, by definition, be mandatory; such actions are prescribed by regulations or rules (Dunster & Dunster 1996).

Habitat: the resources and conditions present in an area that produce occupancy—including survival and reproduction—by an organism (Hall et al. 1997).

Hallux: The first toe, which is reversed in modern birds and used to perch in trees or assist to grip and kill prey in raptors.

Identified wildlife species: a subset of Species at Risk and Regionally Important Wildlife established by the Minister of Water, Land and Air Protection for the Identified Wildlife Management Strategy.

Inter-specific competition: interactions between individuals of different species for limited resources.

Introduced species: a species living outside its native distributional range, which has arrived there by human activity, either deliberate or accidental.

Nest area: contiguous area of suitable goshawk breeding habitat surrounding the cluster of nest trees (see Table 2).

Nest tree: tree containing a goshawk stick nest (see Table 2).

Nest site: forest patch surrounding a nest tree that is thought to capture unique habitat characteristics associated with the nest tree (i.e., nest access, cover, microclimate; see Table 2).

Non-breeding home range: area used by individual goshawks to obtain food during the fall and winter seasons (see Table 2).

Non-colonial: individuals that nest singularly rather than in groups (colonies).

Northern Goshawk *A. g. laingi* Recovery Team habitat suitability and capability prediction models: Mahon et al. (2015) describe the attributes used to model the quality of coastal goshawk nesting and foraging habitat on a scale between 0 (worst) and 1 (best). When the attributes are modelled to predict the current quality of coastal goshawk habitat, this equals habitat suitability. When the attributes are modelled to predict the potential maximum quality habitat condition, either historically or in the future, this equals habitat capability. For example, capable habitats would not include those areas within landscapes that are permanently non-forested such as water bodies, rock, ice, etc., or low productivity, open canopy forests, such as most forested bogs.

Occupancy rate: an *A. g. laingi* nest area or breeding area is considered occupied if at least one adult or fledgling is detected. This metric is calculated using the number of nest/breeding areas with occupied nests divided by the total number of nest/breeding areas assessed for occupancy.

Panmictic: a population where all individuals are potential breeding partners (i.e., there are no group structures or mating restrictions in the population).

Phenotypic/phenotype: the composite of an organism's observable characteristics or traits, such as its morphology, development, biochemical, or physiological properties. A phenotype results from the expression of an organism's genes, as well as the influence of environmental factors and the interactions between the two.

Post-fledging area: area used by fledgling goshawks, within a given year, from fledging until dispersal (see Table 2).

Qualified environmental professional: an applied scientist or technologist who is registered and in good standing with an appropriate provincial legally constituted professional organization. The professional must be acting under that association's code of ethics and subject to the organization's disciplinary action.

Recovery strategy (under the *Species at Risk Act*): detailed plans that outline short-term objectives and long-term goals for protecting and recovering species at risk. Once a species is added to the list and protected officially under the *Species at Risk Act*, a recovery strategy must be developed. For endangered species, this strategy must be developed within 1 year of the listing; for threatened or extirpated (extinct in Canada) species, it must be developed within 2 years.

Red list: includes any indigenous species or subspecies that have, or are candidates for, Extirpated, Endangered, or Threatened status in British Columbia. Extirpated taxa no longer exist in the wild in British Columbia but do occur elsewhere. Endangered taxa face imminent extirpation or extinction. Threatened taxa will likely become endangered if limiting factors are not reversed. Not all red-listed taxa will necessarily become formally designated. Placing taxa on this list flags them as “at risk” and requiring investigation.

Registered Professional Biologist: a biologist registered under British Columbia’s *College of Applied Biology Act*, who acts under the college’s code of ethics and is subject to disciplinary action by the college, and who, through demonstrated suitable education, experience, accreditation, and knowledge relevant to the particular matter, may be reasonably relied on to provide sound advice within their area of expertise.

Registered Professional Forester: a professional forester and a member of the Association of B.C. Forest Professionals. The *Foresters Act*,²⁵ which defines the practice of professional forestry in British Columbia, stipulates that one must be a member of the association to engage in the practice of professional forestry. The Act established the association and charged it with the administration of the *Foresters Act*, vesting all authority to govern the association in its council.

Residence (under the *Species at Risk Act*): a dwelling place, such as a den, nest, or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding, or hibernating.

Risk: can be defined in many ways, but here we define it as the probability of something happening multiplied by the resulting consequence if it does. Risk perception is the subjective judgement people make about the severity and (or) probability of a risk, and varies from person to person.

Satellite nest: single nest tree more than 1000 m from the main cluster of nest trees that typically defines the nest area and breeding area (see Table 2).

Science-based management: This management approach uses two tenets: (1) maximizing the use of local data to guide management, and (2) presenting a range of management options (along with probable consequences) from which qualified environmental professionals can choose.

Sensitive species (U.S. Department of Agriculture, Forest Service in Alaska): species that need special management to maintain and improve their status on National Forests and Grasslands and prevent a need to list them under the United States *Endangered Species Act*.²⁶

Siblicide: the killing of an infant individual by its close relatives (full or half siblings). It may occur directly between siblings or be mediated by the parents.

Significant portion of its range: a portion of the range is significant if its contribution to the viability of the species is so important that without that portion, the species would be in danger of extinction. Biological significance is based on principles of conservation biology, such as redundancy, resilience, and representation. Therefore, a portion of a species range may be determined as “significant” because of its contributions under any one or more of these concepts.

Sink population: a breeding group that does not produce enough offspring to maintain itself in coming years without immigrants from other populations.

Socially monogamous: when individuals pair with the same mate for at least one breeding season.

Source population: a breeding group that produces enough offspring to be self-sustaining and that often produces excess young that must disperse to other areas.

Species of special concern (under the Alaska Department of Fish and Game): as of August 15, 2011, the Alaska Department of Fish and Game no longer maintains a Species of Special Concern list. The list has not been reviewed and revised since 1998 and is no longer considered valid. Since that time, the Department has completed Alaska’s Wildlife Action Plan, which is supported through the State Wildlife Grant program.

Stand-watch surveys: a type of survey method whereby surveyors position themselves at selected vantage points from which suspected nesting habitat is searched for raptors by watching for territorial flights above the canopy and (or) by listening for raptor vocalizations, especially of juveniles begging nearby active nests.

Subspecies: a taxonomic subdivision of a species that includes a group of organisms whose behaviour and (or) genetically encoded morphological and physiological characteristics differ from those of other members of their species. Members of different subspecies of the same species are potentially capable

of breeding with each other and of producing fertile offspring, but there are often geographic, behavioural, or other such “barriers” that minimize interbreeding.

Suitable breeding habitat: habitat ranked by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team breeding habitat suitability model as having a breeding habitat suitability index rating between 0.5 and 1.0.

Suitable foraging habitat: habitat ranked by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team foraging habitat suitability model as having a foraging habitat suitability index rating between 0.5 and 1.0.

Synchronous breeder: individuals of a species that initiate breeding at approximately the same time within the breeding season.

Territory: the total area used by a pair of resident goshawks on an annual basis.

Territory (analysis) model: a model that uses information from nesting and foraging habitat suitability models to predict where sufficient nesting and foraging habitat is present to support a breeding pair of *A. g. laingi* (i.e., territory). This model also uses information about the spacing patterns between adjacent pairs of *A. g. laingi* to predict how many breeding pairs could be supported within a given landscape.

Thermoregulation: the ability of an organism to keep its body temperature within certain boundaries, even when the surrounding temperature is very different.

Threatened (under the Committee on the Status of Endangered Wildlife in Canada): a wildlife species that is likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction.

Threatened (under the United States *Endangered Species Act of 1973*): any species which is “likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.”

Transitional zone: a zone within *A. g. laingi*’s range map presented in the Recovery Strategy for Northern Goshawk, *laingi* subspecies (2008), where coastal habitat types transition to interior habitat types, reflecting an area in which differences between coastal goshawks and interior goshawks *A. g. atricapillus* are likely less clear (see Figure 1).

Turnover rates: this is the fidelity of adult females to breeding areas. It was calculated as the number of consecutive years we observed the same female (identified through banding or tagging) breeding within a given breeding area compared to the number of years we observed different females breeding within the same breeding areas over the years breeding areas were monitored and female identity could be assessed.

Wildlife habitat areas: mapped areas necessary to meet the habitat requirements of an Identified Wildlife element. These areas designate critical habitats in which activities are managed to limit their impact on the Identified Wildlife element for which the area was established. The purpose of these areas is to conserve those habitats considered most limiting to a given Identified Wildlife element.

Appendix 2: Key to Abbreviations of Biogeoclimatic Subzones and Tree Species

SCIENCE-BASED
GUIDELINES
FOR MANAGING
NORTHERN GOSHAWK
BREEDING AREAS

McClaren, Mahon,
Doyle, & Harrower

Key to Biogeoclimatic Zones and Subzones^a

Biogeoclimatic zone		Subzones referenced in report	
CDF	Coastal Douglas-fir		
CWH	Coastal Western Hemlock	dm	Dry Maritime
		ds	Dry Submaritime
		mm	Moist Maritime
		ms	Moist Submaritime
		vh	Very Wet Hypermaritime
		vm	Very Wet Maritime
		wh	Wet Hypermaritime
		ws	Wet Submaritime
		xm	Very Dry Maritime
ESSF	Engelmann Spruce–Subalpine Fir		
IDF	Interior Douglas-fir	ww	Wet Warm
MH	Mountain Hemlock	mm	Moist Maritime

^a A description of the biogeoclimatic classification system in use in British Columbia, including information on biogeoclimatic units, can be found at: <http://www.for.gov.bc.ca/hre/becweb/index.html> and within field guides by Banner et al. (1993) and Green & Klinka (1994).

Key to Tree Codes^a

Tree code	Common name	Species
Ba	amabilis fir	<i>Abies amabilis</i>
Cw	western redcedar	<i>Thuja plicata</i>
Yc	yellow-cedar	<i>Chamaecyparis nootkatensis</i>
Fd	Douglas-fir	<i>Pseudotsuga menziesii</i>
Hw	western hemlock	<i>Tsuga heterophylla</i>
Pl	lodgepole pine	<i>Pinus contorta</i> var. <i>latifolia</i>
Ss	Sitka spruce	<i>Picea sitchensis</i>

^a <http://www.for.gov.bc.ca/hre/becweb/resources/codes-standards/standards-species.html>

1. Numbers of nest trees and nest spacing within breeding areas

Numbers of nest trees and distances between nest trees within the same breeding area are key factors that affect breeding area size. Patterns of nest-tree distribution are also important factors to understand when conducting field surveys to assess the location and extent of a breeding area, as well as designing effective breeding area management strategies. We calculated summary statistics for number of nests for both the full set of 163 breeding areas and for a subset of 63 breeding areas that met the following criteria: (1) had one or more thorough nest search(es) conducted to locate alternative nest trees, and (2) were monitored for at least 3 years. We partitioned the data this way to examine the difference in numbers of nests between breeding areas with a thorough nest search and those without. To quantify patterns of nest spacing within breeding areas, we calculated the Euclidian (straight-line) distances between nest trees in the same breeding area for the full set of 353 goshawk nests within 163 breeding areas. Although breeding areas with incomplete nest searching may have a bias to underestimate nest distances (i.e., because nests farther apart were less likely to have been found), we did not examine this. Distances between nests were calculated in ArcGIS using the “Distances Between Points (within layer)” tool in the “Hawth’s Tools” extension (Beyer 2004).

Breeding areas with a thorough search and at least 3 years of monitoring contained over twice the average number of nest trees than breeding areas with unknown search effort (see Appendix 4: Table A4.1, Figure A4.1). This emphasizes the importance of conducting a thorough inventory to characterize the extent of the breeding area and supports long-term occupancy monitoring to gain a thorough understanding of the breeding area configuration.

2. Distances between neighbouring breeding areas (territory spacing)

Average territory spacing was previously estimated to be 6.9 km on Vancouver Island and 10.9 km on Haida Gwaii (Mahon et al. 2008). These analyses were redone to incorporate new nests within known territories and new territories that had been discovered since the original analyses. Probable neighbours were identified manually for each territory, and distances between breeding area centroids of neighbouring territories were measured in GIS. Probable neighbours were identified as territories within 10.5 km of reference territories on Vancouver Island and within 16 km of reference territories on Haida Gwaii. There were two exceptions: (1) single nests less than 2.5 km from a reference territory were not considered as a neighbour unless both territories were active at the same time (potentially a satellite nest, if not occupied at the same time), and (2) neighbouring territories that were within the maximum distance considered for each study area as being possible nearest neighbours were excluded if another territory occurred between them.

Based on this updated analysis, the average territory spacing distances of 6.9 km on Vancouver Island and 10.4 km on Haida Gwaii were very similar to previous estimates (Mahon et al. 2015).

3. Distances of coastal goshawk nests from cutblocks

Mahon et al. (2008) estimated that very low and low numbers of nests were located within 100 m and 200 m of cutblock edges, respectively, for 148 nests on Vancouver Island. For this report, we re-analyzed the distance goshawk nest trees were from cutblock edges using

an expanded database that consisted of 283 goshawk nest tree locations (2013 database) for Vancouver Island and Haida Gwaii. The full set of 353 nest trees was not used because cutblock data were unavailable for some areas.

Measuring distance of nests to cutblocks involved a two-stage process. First, we were provided with distance of nests to nearest cutblocks calculated by Ministry of Forests, Lands and Natural Resource Operations GIS staff. This analysis used all cutblocks in the harvest depletion layer, irrespective of year of nest discovery or year of cutblock harvest. In many cases, the cutblock used for the measurement was closer to the nest than cutblocks actually present at the time the nest was discovered. Further, in several cases, erroneous distances of zero were recorded where a nest occurred in a Wildlife Tree Patch or the reference cutblock was not yet logged. To address this issue, we manually assessed the distance of all nests where the initial GIS query estimate was less than 200 m and, where appropriate, re-measured the nest to cutblock distance using cutblocks present at the time the nest was first discovered. Cutblock age was based on the “date of harvesting completed” field in the cutblock depletion layer. We chose 200 m as the cut-off for manual cutblock edge assessment because this represented the farthest distance predicted to reduce nesting habitat suitability from edge effects (Mahon et al. 2015). All nests from the South Coast and North Coast were excluded from the final sample because of uncertainty about nest locations, poor cutblock data, or time limitations.

To compare the observed distribution of distances of nests from cutblock edges to what was available, we also measured distances of 5000 random points to cutblock edges on Vancouver Island. The criteria used to define the sample area for random points were: (1) the CWH zone, and (2) tenure areas with cutblock data from the GIS depletion layer. All cutblocks from 1975 to current were included in the analysis of distance of random points to cutblocks. Cutblocks older than 1975 were excluded because these would have regenerated to the point where they no longer created a hard edge with adjacent mature forest during the period of goshawk nest inventory (~1995 to present).

4. Foraging habitat analysis: Daust et al. (2010)

A circular-shaped territory of 3745 ha (Vancouver Island Conservation Region/South Coast Conservation Region) or 9160 ha (Haida Gwaii Conservation Region/North Coast Conservation Region) was placed around known nests (centred on geographic mean of nest cluster in each territory) and 25 randomly located nest centroids in each study area. The amount of suitable foraging habitat (as predicted by the model) within circles was then calculated in known compared to random sites. Randomly generated centroids were located in nesting habitats with a habitat suitability index of greater than 0.5 (suitable) and within suitable patch sizes greater than 50 ha (as in the territory model). The calculation of suitable foraging habitat within circles classified foraging habitat into nil (habitat suitability index 0–0.24), low, moderate, and high suitability classes. To calculate the percent of the circle in suitable foraging habitat, the total area within suitable habitats was divided by the total area. Therefore, water, non-productive forest, and other non-habitat types were included in the total area denominator. As well, the total hectare amounts were not weighted to account for their habitat suitability score. To generate the graph in Daust et al. 2010, only known goshawk territories within Haida Gwaii and Vancouver Island study areas were incorporated, because these areas included long-term monitoring programs, whereas other conservation regions did not have these data. As well, within Vancouver Island and Haida Gwaii conservation regions, only those territories that were monitored for a minimum of 3 years after initial location and were occupied for at least one of those



years were included. We felt that without this monitoring and occupancy information, we may include breeding areas in the analysis that were no longer suitable. It is important to note, however, that the time series for when goshawks were occupying nest areas and the foraging habitat suitability forest cover data sets were not the same. For this analysis, forest cover data for the Vancouver Island Conservation Region was either 2003 (Timber Farm Licences) or 2009 (Timber Supply Areas) and for Haida Gwaii it was from approximately 2006. Therefore, this analysis likely underestimates the actual amounts of suitable foraging habitat within territories at the time occupancy data were collected.

5. Foraging habitat analysis: Smith & Vennesland (unpublished data)

- The sample included 82 territories on Vancouver Island and 18 on Haida Gwaii. This represented all territories for which habitat information was available to run the models.
- Only known territories were used for this analysis, not predicted ones.
- Modelled territories were “grown out” by the territory model from the centre of the nest tree cluster (see Smith & Sutherland 2008 for details).
- Maximum territory size was 4616 ha on Vancouver Island and 11 310 ha on Haida Gwaii.
- The proportion of suitable habitat currently available was calculated by adding the amount (in hectares) of medium- and high-rated foraging habitat according to the model developed by Mahon et al. (2015) and was mapped with the most recent forest cover data available; this was then divided by the total estimated territory area.
- The historical landscape condition was estimated by modelling the amount of suitable habitat that should have been available if all capable habitat was suitable. This modelling process is referred to as “backcasting” (Smith & Sutherland 2008). Capable habitat includes all “forest” having the characteristics outlined by Mahon et al. (2015) for high- or moderate-foraging habitat suitability, even if it is currently too young to be suitable. Capable habitat would not include permanently non-forested sites, such as water bodies, alpine areas, sub-alpine forests, etc. The amount of historically available foraging habitat was calculated as the proportion of a goshawk territory that is capable, divided by the total area of the maximum territory size (see above).

When a goshawk breeding area is first located, the discovery is often of a defensive adult bird(s) protecting its nest or young. This limited information is inadequate to define the boundaries of the breeding area. Systematic surveys by a qualified environmental professional with goshawk expertise are required to identify historic and current nests, as well as potential future nest tree opportunities. In addition, suitable breeding habitat that may serve as post-fledging areas around these nest trees and that can provide nest tree edge buffers and connectivity (as described in Section 8.3 on reserve design) should be identified. The objectives of the initial breeding area survey are to: (1) locate as many nest trees as possible, and (2) document the characteristics of the forest at nest sites and the extent of similar forest surrounding those nests.

1. Breeding Area Survey Methods: Overview

Field surveys to define the breeding area consist of: (1) systematic, visual searching for goshawk nests and goshawk sign (plucking posts, moulted adult feathers or down from fledglings, concentrations of white wash excrement, typically under active nest trees and plucking posts); and (2) broadcast surveys to locate breeding adult goshawks or their young (see B.C. Ministry of Sustainable Resource Management 2001; McClaren et al. 2003 for detailed survey protocols). Normally, surveys should be conducted during the breeding season but if a nest, aggressive adults, or juvenile locations are known, nest searching and identification of suitable breeding habitat around those areas outside the breeding season may be sufficient to locate alternative nests to initially define the breeding area. All forest that is potentially suitable for nesting (see Section 5) should be surveyed within a radius of approximately 800–1500 m surrounding the observed nest(s) or goshawk sighting(s), and the search area should be expanded an additional 800–1500 m around additional nests that are found. The appropriate search radius depends on the distribution of suitable breeding habitat in the area—1000 m is normally adequate in areas dominated by relatively continuous breeding or post-fledging area habitat types; 1500 m is more appropriate in areas where potential breeding habitat is dispersed and fragmented owing to logging or natural terrain and vegetation patterns (e.g., large, steep gully systems, lakes, or lowland bog forests). Visual searches for alternative nests should follow systematic transects spaced 40–80 m apart, depending on forest structure and resulting sight lines, to provide relatively thorough coverage of the search area (transects need not be flagged; compass and GPS navigation are adequate). Nest searching consists of visually searching the canopy for nests and the ground for breeding sign as observers walk along transects. It is important to stop frequently and scan a full 360° field of view to obtain multiple sight angles through the forest; nests are frequently missed if an observer limits their view to their direction of travel. Multiple visits on two or more days during the breeding season can increase the chances of viewing goshawk behaviour that will lead to nest locations, especially when birds are difficult to detect (i.e., incubation) or extremely agitated and flying around a large area.

The required survey time to define a breeding area will vary depending on terrain, forest structure, and number of alternative nest trees. Emphasis should be placed on appropriate coverage of the potential area (described above) versus search time. Our experience in coastal British Columbia suggests that a qualified environmental professional and assistant can normally survey a large enough area and locate a representative sample of nests to enable defining the breeding area within approximately 1–2 days (i.e., 8–16 hours). Additional search effort is usually beneficial if resources are available.

2. Assessing Breeding Area Occupancy Status

Once goshawk breeding areas are located, it is often desirable to assess a sample of breeding areas for their occupancy status annually; the goal of these assessments may be for long-term monitoring (see detailed protocol in Darling 2010) or because resource development activities nearby need to ensure their development will not cause disturbance to nearby active nests. The following protocols outline the survey requirements needed to assess these.

The first stage of breeding area occupancy assessment is to check for goshawk activity at known nest sites; broadcast surveys should only be used after all known nests are assessed for activity to avoid causing the potential behavioural disturbance associated with these. Although assessing nest activity may seem straightforward, an incubating or brooding goshawk can be secretive and quite difficult to detect in the nest. Observers should use high-powered binoculars, or a spotting scope, to scan all known nests from multiple angles for signs of breeding activity. Observations from upslope typically provide better angles for viewing into nests. Signs associated with active nests may include:

- an adult goshawk sitting on the nest;
- chicks inside nests or on nest tree branches;
- the presence of down (moulted breast feathers) along the rim of the nest;
- fresh greenery added to the nest;
- the presence of white wash at the base of the nest tree (indicates nestlings are present);
- fresh prey remains or plucking posts near the nest tree;
- regurgitated pellets at the base of the nest tree;
- moulted adult flight feathers near the nest tree; and
- fledglings within breeding areas.

If none of the previously known nests appears to be active, broadcast surveys using recordings of goshawk calls are required to locate other active nest trees within breeding areas (see B.C. Ministry of Sustainable Resource Management 2001; McClaren et al. 2003 for detailed survey protocols).

Detectability of goshawks using broadcast surveys varies across the four breeding stages (courtship, incubation, nestling, post-fledging), and presence or absence (not detected) results must be interpreted differently for each period. Ultimately, “not breeding” or “unoccupied” status can only be inferred with a high degree of confidence when breeding goshawks continue to be undetected after repeated nest status surveys during the nestling (May 25–June 30) and post-fledging periods (July 1–September 15). The presence of an incubating female during the incubation period (Apr 20–May 25) verifies occupancy and nest initiation but cannot be used to verify nest success or the number of young fledged as nests may still be abandoned and (or) young may not survive after this stage. Failure to detect goshawks during the incubation period cannot determine that breeding areas are unoccupied because breeding birds may be using a previously unknown nest and individuals can be secretive at this time, resulting in low detection rates from broadcast surveys (see Kennedy & Stahlecker 1993). Occupancy assessments during the courtship period (Feb 15–Apr 20) are only recommended if the goal is to determine occupancy status early; however, detection rates during this time are highly variable and presence only confirms territory occupancy and not whether the breeding area will have an active nest that year (Zeeman 2003; McClaren et al. 2003).

A *minimum* of two broadcast surveys on foot on different days are required to infer “not breeding” or “unoccupied” status of a goshawk breeding area. Broadcast surveys from roads alone will not suffice in determining occupancy status; surveyors must conduct searches for new nests and occupancy sign within the forest, commensurate with the methods and intensity described above, for initial breeding area nest searches. Preferably, surveys should be conducted in both the nestling and post-fledging periods, but two surveys during the nestling period may be acceptable for managers willing to accept a higher risk that active nests may go undetected. A trade-off exists between balancing the probability of detecting occupancy with that of locating active nest trees. During the nestling phase, the probability of detecting goshawks is lower than during the post-fledging period (McClaren et al. 2003). However, the probability of locating active nests is higher during the early nestling period (June 1–15) when adults are most aggressively defending young and are typically within 200 m of active nests when detected (McClaren et al. 2003).

If an adult goshawk is detected sitting on or in a nest, or if chicks are observed in a nest, occupancy is confirmed and the survey for that breeding area can be stopped. If goshawks are not present at any of the known nests, broadcast surveys and searching for alternative nests should be conducted as outlined above in the “Breeding Area Survey Methods” section. Normally, survey of known nests should be conducted before call-playback surveys to avoid causing the potential behavioural disturbance associated with call-playback surveys.

3. Qualifications of Personnel for Breeding Area Surveys and Occupancy Assessments

Successful inventory and monitoring of goshawk breeding areas, especially locating new nests, is highly dependent on the knowledge and experience of field personnel (Table A4.1; Figure A4.1). Although goshawks are easily detected when exhibiting defensive behaviours near nest sites, goshawks can also be quite secretive at nests (especially during incubation) and key signs associated with breeding can be easily overlooked by inexperienced personnel.

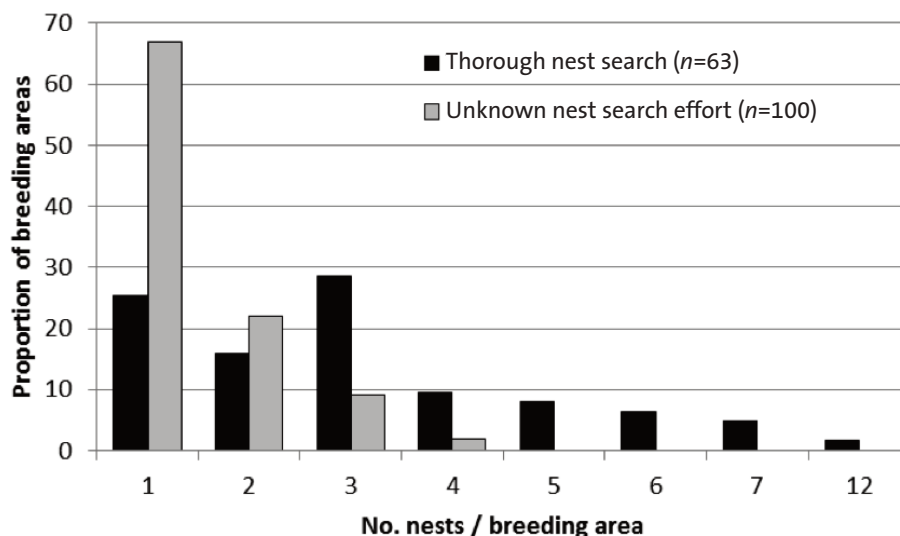
Crew leaders or field personnel working alone should be qualified (trained and experienced) in the following areas:

- raptor identification;
- the range of goshawk vocalizations;
- mimics of goshawk vocalizations (e.g., gray jays);
- breeding area sign (white wash, goshawk feathers, plucking posts, pellets);
- broadcast survey techniques; and
- nest searching techniques.

Table A4.1. Number of nest trees located in coastal goshawk breeding areas relative to whether a thorough nest search was conducted.

Sample	No. nests	No. breeding areas	Mean	SE	Min	Max	Mode
All breeding areas	353	163	2.13	0.13	1	12	1
Breeding areas with full search + 3 years of monitoring	194	63	3.01	0.25	1	12	3
Breeding areas with unknown search effort	159	100	1.46	0.07	1	4	1

Figure A4.1 Differences in numbers of nests within 163 coastal goshawk breeding areas in British Columbia relative to whether a thorough nest search was conducted. “Thorough nest search” means a comprehensive search or survey within 800 m of each previously known nest and three or more years of monitoring.



Generally, competency in these areas is associated with training by a goshawk specialist and at least one season of goshawk inventory or monitoring work, which includes several aural and visual detections of goshawks and observation of several goshawk nest sites.

Key Points

- Following a goshawk detection (aural/visual), breeding area boundaries should be delineated by a qualified environmental professional who has goshawk experience. Locate nests using systematic visual searches in combination with broadcast surveys using goshawk calls.
- Qualified environmental professionals assessing occupancy of a previously known breeding area should consider variation in goshawk detectability across the breeding season. Detection rates are highest during the post-fledging period (July 1–September 15) and lowest during incubation (April 20–May 25). The probability of locating active nests is highest during the early nestling phase (June 1–15).
- The timing and intensity of breeding area occupancy assessments depends on survey objectives, budgets and risk tolerances set by qualified environmental professionals and resource managers; a higher risk tolerance may lead to fewer assessments and a greater likelihood of missing active nests.

Author Information

SCIENCE-BASED GUIDELINES FOR MANAGING NORTHERN GOSHAWK BREEDING AREAS

McClaren, Mahon,
Doyle, & Harrower



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April 2018

Ketchikan Summer Visitor Profile and Economic Impact Analysis

Prepared for
Ketchikan Visitors Bureau



Prepared by


McDowell
GROUP

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Table of Contents

Introduction and Methodology 1

Visitor Volume 8

Visitor Profile 10

 Alaska Trip Purpose and Packages10

 Length of Stay, Lodging, and Destinations11

 Activities14

 Satisfaction Ratings.....15

 Previous and Future Alaska Travel17

 Trip Planning19

 Supplemental Data on Usage of KVB Information Sources by Cruise Passengers.....31

 Demographics.....25

 Visitor Spending.....29

Economic Impact Analysis..... 31

 Direct Spending and Impacts.....34

 Total Economic Impacts36

 Role in the Ketchikan Economy.....36

 Trends in Impacts38

 Municipal Revenues.....39

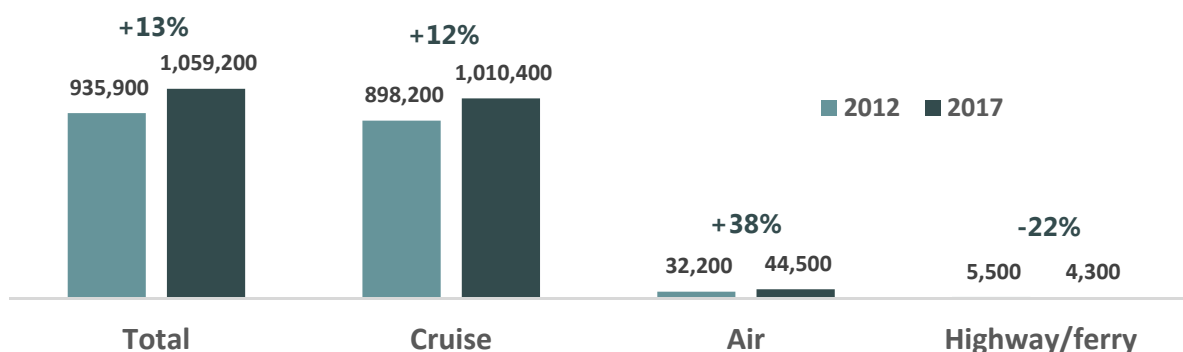
Executive Summary

The Ketchikan Visitors Bureau contracted with the McDowell Group to profile summer visitors to Ketchikan. This study presents results for all Ketchikan visitors, as well as for subgroups based on the mode of travel, and two additional markets: non-cruise visitors traveling for vacation/pleasure, and a subset of these visitors from Western U.S. states. The report includes an estimate of visitor volume for summer 2017, and concludes with an analysis of economic impacts resulting from spending by visitors in summer 2017, including employment, labor income, and municipal tax revenues. Sources included the *Alaska Visitor Statistics Program*, City and Borough tax and budget documents, Alaska Department of Labor and Workforce Development, and Bureau of Economic Analysis, among others. Following are key findings from the study.

Visitor Volume

An estimated 1,059,200 out-of-state visitors traveled to Ketchikan in summer 2017. Nearly all of them (95 percent) visited by cruise ship; 4 percent visited by air; and 1 percent visited by ferry. Between summer 2012 (the study period of the last economic impact report) and summer 2017, visitor volume increased by 13 percent. Cruise passenger volume increased by 12 percent, air volume increased by 38 percent, and ferry traffic decreased by 22 percent.

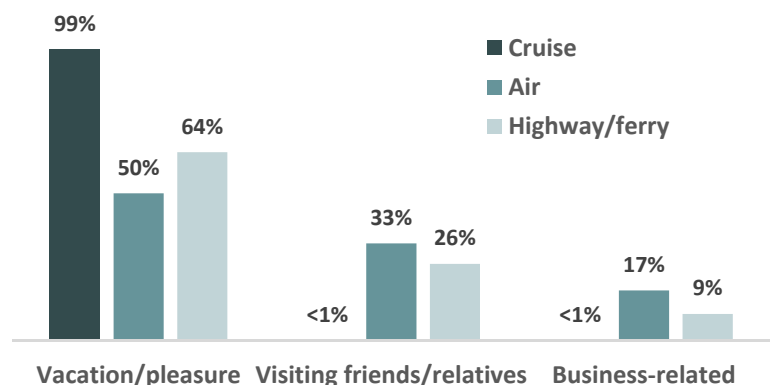
Chart ES-1. Summer Visitor Volume to Ketchikan, 2012 and 2017, by Transportation Market



Trip Purpose

Cruise passengers were nearly all (99 percent) traveling to Alaska for vacation/pleasure. Among air visitors, 50 percent were traveling for vacation/pleasure; 33 percent to visit friends/relatives; and 17 percent for business-related reasons. Among highway/ferry visitors, 64 percent were traveling for vacation/pleasure; 26 percent to visit friends/relatives; and 9 percent for business-related reasons.

Chart ES-2. Alaska Trip Purpose by Transportation Market



Activities

Activity participation varied significantly by transportation market.

Cruise visitors' top activities were city/sightseeing tours (23 percent), wildlife viewing (12 percent), and shows/entertainment (12 percent). (The entertainment category includes the Lumberjack Show.) Cruise visitors were less likely than non-cruise visitors to participate in fishing and museums.

Air visitors showed a high rate of participation in fishing (43 percent). This includes 20 percent who reported guided fishing and 25 percent who reported unguided; a few reported both. Their other common activities included hiking/ nature walk (24 percent), wildlife viewing (21 percent), and museums (13 percent). Among the three markets, air visitors were the most likely to participate in fishing.

Highway/ferry visitors tended to report the widest range of activities. Their most common activities were wildlife viewing (29 percent), museums (28 percent), hiking/nature walk (26 percent), and fishing (26 percent). They were more likely than either cruise or air visitors to report wildlife viewing, museums, historical/cultural attractions, and camping.

It should be noted that the AVSP did not collect participation in shopping at a community level. Statewide, it is the number one activity among all visitors at 75 percent. Among Ketchikan visitors, 84 percent reported shopping while on their Alaska trip.

Chart ES-3. Top Ketchikan Activities, Cruise Visitors

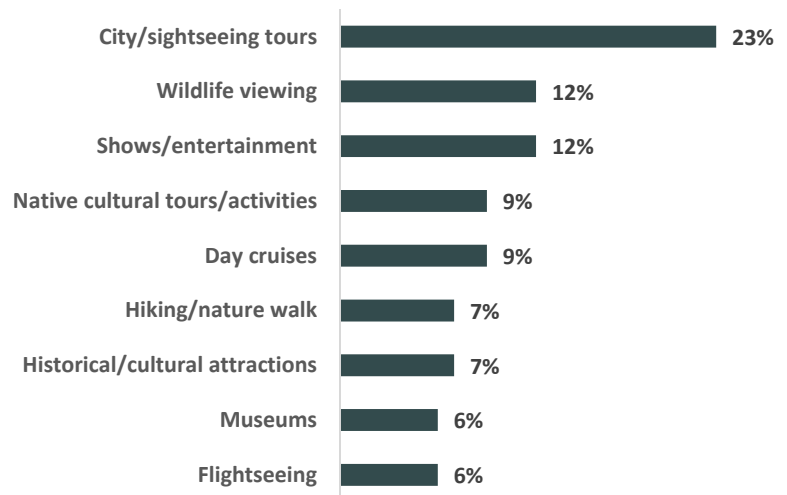


Chart ES-4. Top Ketchikan Activities, Air Visitors

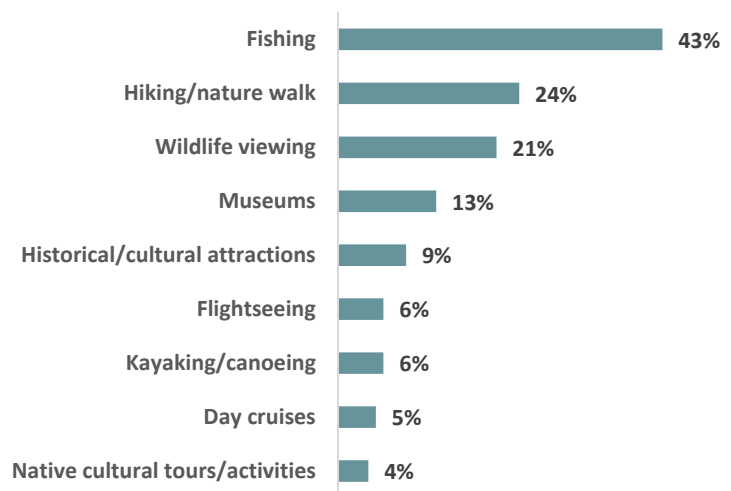
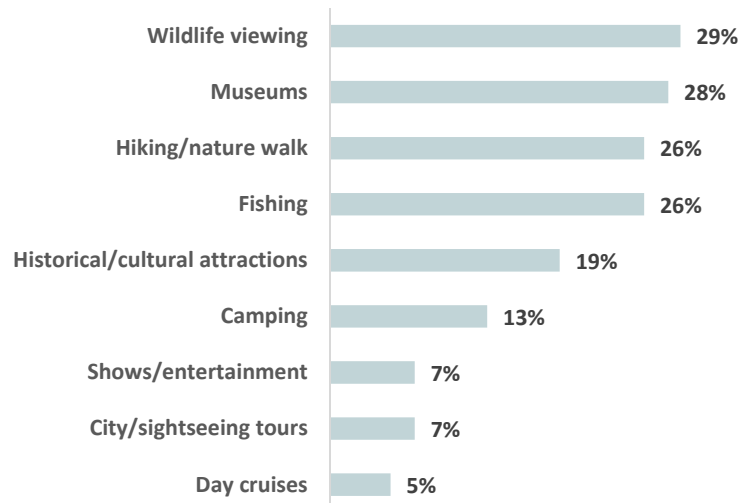


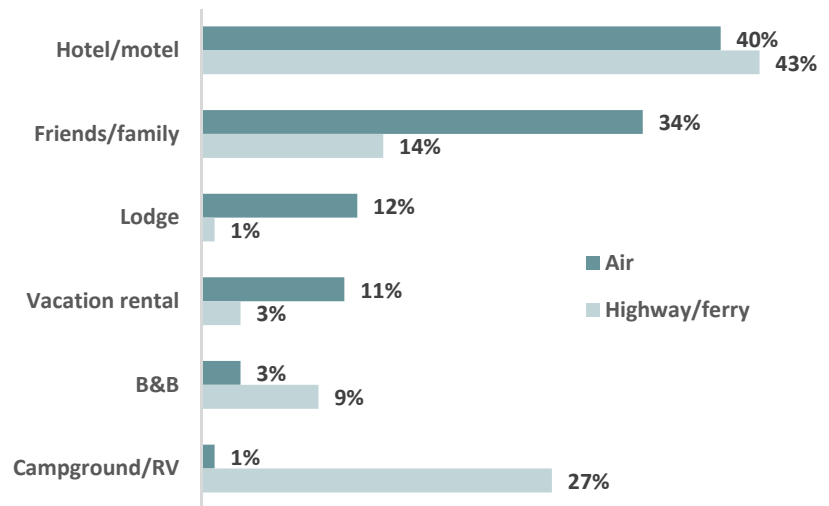
Chart ES-5. Top Ketchikan Activities, Hwy/Ferry Visitors



Lodging

The most common lodging option among Ketchikan's overnight visitors was hotels/motels, with air and highway/ferry visitors equally likely to use this option (40 and 43 percent). Air visitors also frequently stayed with friends/family (34 percent), in lodges (12 percent), and in vacation rentals (11 percent). Ferry visitors were much more likely to stay in campgrounds/RVs (27 percent, versus 1 percent of air visitors). Ferry visitors also stayed with friends/family (14 percent) and in B&Bs (9 percent).

Chart ES-6. Ketchikan Lodging by Transportation Market



Trip Planning

Visitors were asked two questions about the timing of planning their Alaska trip: how many months before traveling had they made the decision to travel to Alaska, and how many months before traveling had they booked their major travel arrangements. Cruise passengers showed the longest lead time for both trip decision (average 8.8 months) and booking (6.6 months). Air visitors reported an average lead time for the trip decision of 6.0 months, and average booking lead time of 4.1 months. Highway/ferry visitors reported making their decision an average of 7.5 months ahead of time and booking only 3.3 months ahead of time.

Chart ES-7. Trip Planning Timeline By Transportation Market

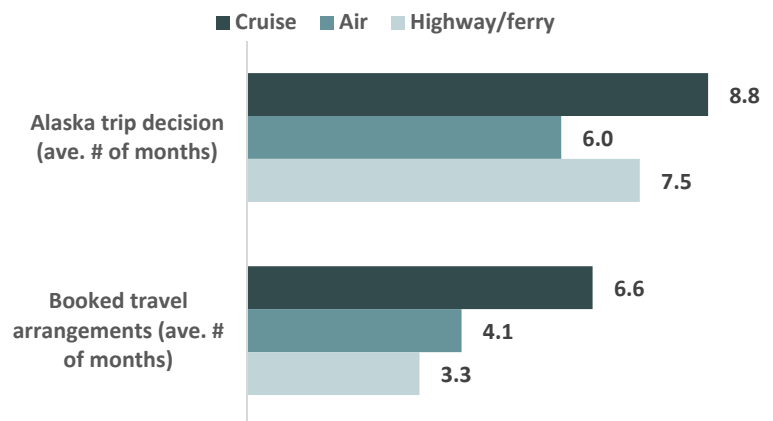
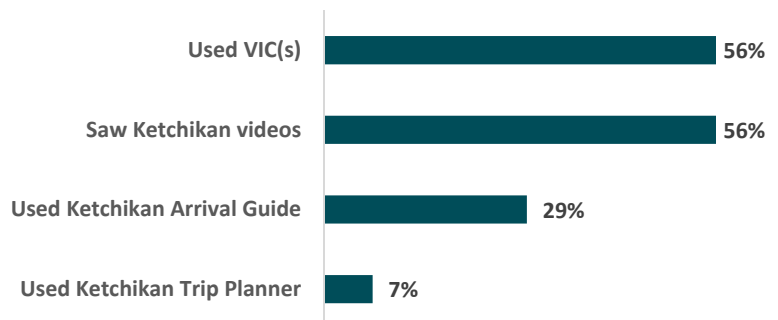


Chart ES-8. Usage of KVB Information Sources (KGB Cruise Passenger Survey)



A cruise passenger survey conducted for the Ketchikan Gateway Borough in summer 2016 reveals specific information on usage of KVB sources. The survey showed that over half of cruise ship passengers (56 percent) reported using at least one of the Visitor Information Centers (VICs). The same proportion (56 percent) reported seeing Ketchikan videos, either before their trip, onboard their ship, or while they were in Ketchikan. Nearly one-third of passengers (29 percent) said they used the Ketchikan Arrival Guide, and 7 percent said they used the Ketchikan Trip Planner.

Visitor Spending

Spending in Ketchikan varied widely by transportation market. Air visitors reported the highest average spending per person, at \$872, followed by highway/ferry at \$580 and cruise passengers at \$158. Air visitors spending was concentrated largely in lodging (\$207), food/beverage (\$167), and other/packages (\$281). Cruise visitors' spending was concentrated in gifts/souvenirs (\$87) and tours (\$60). Highway/ferry visitors' spending was concentrated in lodging (\$187) and food/beverage (\$181).

Table ES-1. Visitor Expenditures in Ketchikan, Per Person Per Trip

	Transportation Mode		
	Air	Cruise	Hwy/Ferry
Lodging	\$ 207	\$ 0	\$ 187
Tours/activities/entertainment	\$ 63	\$ 60	\$ 72
Gifts/souvenirs/clothing	\$ 92	\$ 87	\$ 55
Food/beverage	\$ 167	\$ 10	\$ 181
Rental cars/fuel/transportation	\$ 62	\$ 1	\$ 58
Other/packages	\$ 281	\$ 0	\$ 27
Total	\$ 872	\$ 158	\$ 580

Economic Impacts

Economic impacts are generally considered in terms of "direct" and "total" (including indirect) impacts. Direct impacts include spending by visitors, cruise lines, and cruise ship crew members.

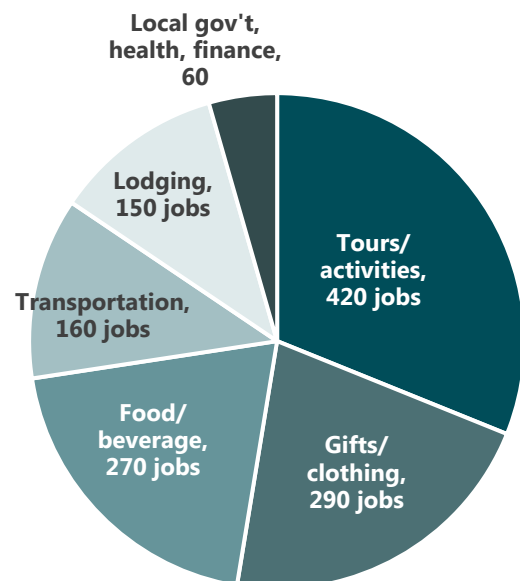
Total direct spending in summer 2017 is estimated at \$223 million, including \$187 million by visitors, \$29 million by cruise lines, and \$7 million by crew members. Visitor spending was determined using spending averages from survey results, with adjustments made to account for commissions on tours that accrue directly to cruise lines.

This direct spending translates into employment of 1,350 jobs, and direct labor income of \$57 million. Jobs are spread throughout Ketchikan's economy, with 31 percent attributable to the tour sector; 21 percent attributable to gifts, souvenirs, and clothing; 20 percent attributable to food/beverage; 12 percent attributable to transportation (including rental cars and fuel); 11 percent attributable to lodging; and 4 percent attributable to local government/health care/finance.

Table ES-2. Direct Visitor Industry Impacts, Summer 2017

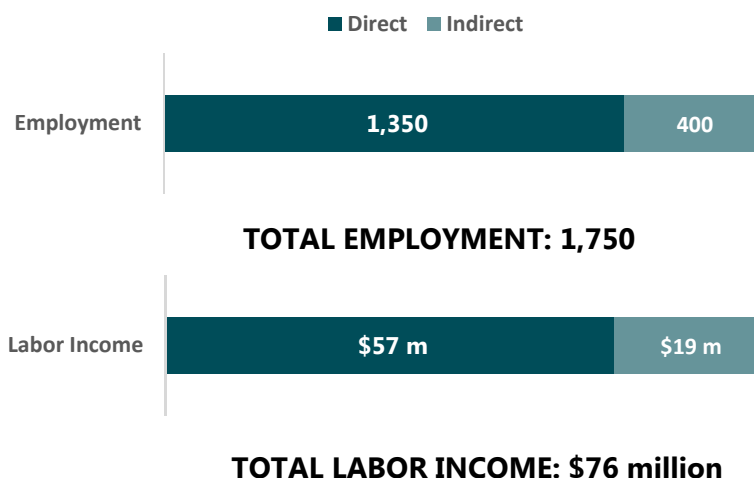
	Spending
Visitors	\$187 million
Cruise lines	\$29 million
Crew members	\$7 million
Direct Spending	\$223 million
Direct Employment	1,350 jobs
Direct Labor Income	\$57 million

Chart ES-8. Direct Employment Resulting from Industry Spending, By Sector, Summer 2017



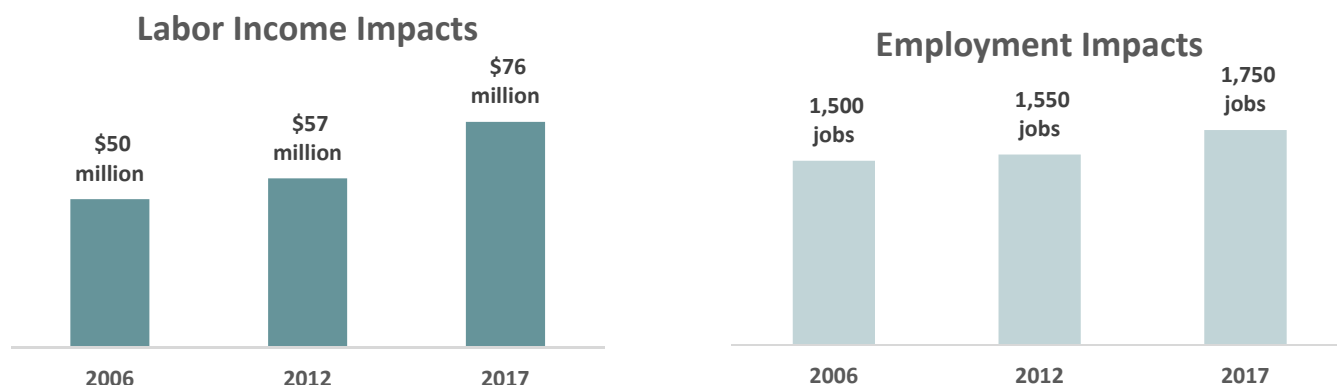
Direct employment and labor income estimates do not include multiplier effects, i.e., those jobs and income created in Ketchikan as the visitor dollar is re-spent by visitor industry businesses and their employees. This secondary spending is estimated to result in 400 jobs and \$19 million in labor income during the summer 2017 study period. Adding secondary impacts to the initial direct impacts of 1,350 jobs and \$57 million in labor income indicates total direct, indirect and induced impacts of 1,750 jobs and \$76 million in labor income.

Chart ES-9. Direct, Indirect, and Total Employment and Labor Income Resulting from Visitor Industry in Ketchikan, Summer 2017



This is the third study of the economic impacts of Ketchikan's summer visitor industry. The charts below show how impacts have increased since the first report in 2006. Labor income impacts increased by 52 percent between 2006 and 2017, in nominal terms; after adjusting for inflation, the increase is 23 percent. Employment increased by 17 percent between 2006 and 2017.

Chart ES-10. Employment and Labor Income Impacts from Ketchikan's Summer Visitor Industry, 2006, 2012, 2017



Municipal Revenues

The visitor industry generated nearly \$19 million in revenues to the Ketchikan Borough and City of Ketchikan, in the form of wharfage/fees, CPV taxes, sales taxes, and bed taxes. Spending by summer visitors, cruise lines, and crew members contributed an estimated \$5.1 million in sales taxes, and \$300,000 in bed taxes. The City of Ketchikan collected \$9.0 million in dockage/moorage fees, and the City/Borough combined collected \$4.3 million from the statewide Commercial Passenger Vessel tax.

Table ES-3. Selected Municipal Revenues from Summer Visitor Industry, 2017

Revenues	
Sales tax revenues	\$5.1 million
Bed tax revenues	\$0.3 million
Wharfage/fees	\$9.0 million
CPV payments	\$4.3 million
Total	\$18.7 million

Introduction and Methodology

Introduction

The Ketchikan Visitors Bureau contracted with the McDowell Group to profile summer 2016 visitors to Ketchikan based on data from the *Alaska Visitor Statistics Program 7* (AVSP). AVSP is a statewide survey of out-of-state visitors commissioned by the Alaska Department of Commerce, Community, and Economic Development and the Alaska Travel Industry Association. AVSP 7 included surveys of 2,277 out-of-state travelers who visited Ketchikan either for a day or overnight visit, between May and September 2016.

This study presents results for all Ketchikan visitors, as well as for subgroups based on the mode of travel (air, cruise, highway/ferry), and two additional markets of interest to KVB: non-cruise visitors traveling for vacation/pleasure purposes, and a subset of these visitors, those from Western U.S. states.

The report includes an estimate of visitor traffic for summer 2017, and concludes with an analysis of economic impacts resulting from spending by visitors in summer 2017, including employment, labor income, and municipal tax revenues. This is the fourth study of visitor industry economic impacts conducted by McDowell Group for KVB; the previous study measured impacts from visitors in summer 2012.

Methodology

Visitor Traffic

Visitor volume was estimated based on the AVSP study, which included visitor traffic estimates to various communities and regions in Alaska. Additional sources included air passenger enplanement data from the Ketchikan Airport, ferry embarkations from Alaska Marine Highway System, and cruise passenger traffic data from Cruise Line Agencies of Alaska.

Visitor Profile

The AVSP visitor survey is administered to a random sample of out-of-state visitors departing Alaska at all major exit ports, including airports, highways, cruise ship docks, and ferries. The survey includes questions on trip purpose, transportation modes, length of stay, destinations, lodging, activities, expenditures, satisfaction, trip planning, and demographics. The summer 2016 AVSP included surveys of 5,926 out-of-state visitors to Alaska, including 2,277 who visited Ketchikan. Nearly all (96 percent) of Ketchikan visitor surveys were conducted in person, with the remainder filling out the survey online (survey invitation cards were distributed at Anchorage Airport). All data is weighted by transportation mode according to estimated traffic by month and location.

The table on the following page shows how each market is defined for purposes of this study, along with their respective sample size, estimated volume, and maximum margin of error. The non-cruise submarkets (Air, Highway/Ferry, Non-Cruise V/P, and Non-Cruise V/P West Only) include only visitors who overnighted in Ketchikan. Those who stopped in Ketchikan during the day only, for example those traveling on to sportfishing lodges, are excluded from these profiles.

Note that the highway/ferry market includes any visitor who entered or exited *Alaska* via highway or ferry; some highway/ferry visitors may have traveled to Ketchikan via air. Likewise, the air visitor market may include some visitors who traveled to Ketchikan via ferry.

Table 1. Sample Sizes and Margins of Error

	Sample Size	Maximum Margin of Error
All Visitors – Traveled to Ketchikan, either day or overnight	2,277	±2.1%
Air - Entered <i>and</i> exited Alaska by air; spent at least one night in Ketchikan; excludes cruise passengers	222	±6.6%
Cruise - Spent at least one night aboard a cruise ship	1,814	±2.3%
Highway/Ferry - Entered <i>or</i> exited Alaska by highway <i>or</i> ferry; spent at least one night in Ketchikan; excludes cruise passengers	121	±8.7%
Non-Cruise V/P - Traveled to Alaska for vacation/pleasure purposes; spent at least one night in Ketchikan; excludes cruise ship passengers	187	±7.1%
Non-Cruise V/P, West Only – Same as above, from Western U.S. states	117	±9.0%

The Visitor Profile chapter includes supplemental information from a survey of Ketchikan cruise passengers conducted by McDowell Group for the Ketchikan Gateway Borough in summer 2016 (the same time period as AVSP). This survey offers useful information on trip planning that is specific to Ketchikan, and includes sources used during the passengers' trip.

Economic Impact Analysis

This economic impact analysis estimates employment and labor income resulting from visitor spending in Ketchikan during summer 2017. Average visitor spending by category/sector was based on AVSP survey results and applied to visitor volume to arrive at total direct spending and employment estimates. Cruise ship crew member spending was based on a survey of crew members conducted by McDowell Group in summer 2016 as part of a larger project for the Ketchikan Gateway Borough. Cruise line spending was estimated by applying the percentage increase in the number of cruise line calls between 2012 and 2017 to previous figures.

McDowell Group developed a custom model for estimating multiplier effects. The econometric modeling program IMPLAN was used to estimate specific model inputs.

Additional sources included:

- Alaska Department of Labor and Workforce Development for employment and wage data
- U.S. Bureau of Economic Analysis for employment and wage data
- Ketchikan Gateway Borough and City of Ketchikan gross sales data for visitor-affected categories
- Borough and City bed tax revenues
- Ketchikan Gateway Borough for payments from cruise lines for moorage, docking, etc.
- Commercial Passenger Vessel Tax documents
- Borough and City budget documents
- Alaska Department of Revenue Shared Taxes and Fees Annual Reports

Visitor Volume

An estimated 1,059,200 out-of-state visitors traveled to Ketchikan in summer 2017. Nearly all of them (95 percent) visited by cruise ship; 4 percent visited by air; and 1 percent visited by ferry.

Between summer 2012 (the study period of the last economic impact report) and summer 2017, visitor volume increased by 13 percent, from 935,900 to 1,059,200. Most of this increase is attributable to cruise passenger volume, which increased by 12 percent over the period. While representing a much smaller number of visitors, air volume increased at an even higher rate: 38 percent, from 32,200 to 44,500. Ferry traffic was the only mode that showed a decrease: by 22 percent, from 5,500 to 4,300.

Chart 1. Visitor Volume to Ketchikan By Transportation Mode, Summer 2017

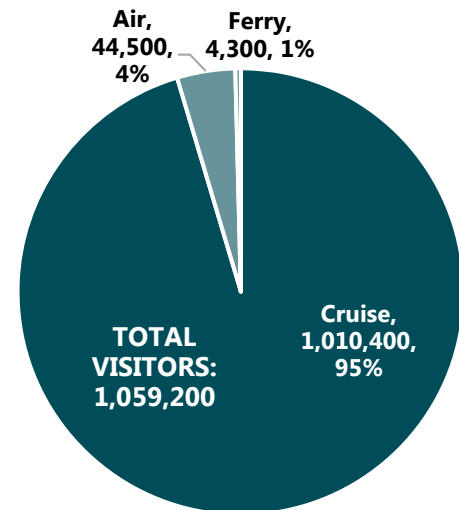


Table 2. Visitor Volume to Ketchikan by Transportation Mode, Summers 2012 and 2017

	Summer 2012	Summer 2017	% Change
Cruise	898,200	1,010,400	+12%
Air	32,200	44,500	+38%
Ferry	5,500	4,300	-22%
Total	935,900	1,059,200	+13%

An additional source of out-of-state spending incorporated into the subsequent economic impact analysis is cruise ship crew members. Based on the 2017 Ketchikan cruise ship calendar, an estimated 26,000 crew members visited Ketchikan in summer 2017, up 13 percent from 23,000 in summer 2012.

Further sources of visitors that are not measured in this report, but nonetheless contribute to Ketchikan's visitor economy, include:

- **Convention/meeting attendees:** Ketchikan Visitors Bureau tracks meetings, conferences, and sports-related events as well as their local impact. In 2017, KVB estimated that 17,174 people participated in 58 events, representing 3,856 bed nights. (Most attendees are local.) Assuming a per-bed-night impact of \$279 per attendee, impacts are estimated at \$1,076,000. Because not all meetings are reported to KVB, this estimate should be considered conservative.
- **Fall/winter/spring visitors:** Research on Alaska's fall/winter/spring visitor market has not been conducted since 2011-12. As reported in the last economic impact report, Ketchikan received an estimated 10,000 visitors in the 2011-12 October to May period. These visitors spent an estimated \$4.2 million in Ketchikan.

- **In-state visitors:** Unfortunately, there is little research on travel by Alaska residents within the state. Alaska residents traveling to Ketchikan are likely to be traveling for business purposes, including meetings/conferences, although many residents of outlying communities also travel to Ketchikan for shopping, medical, and/or to visit friends/relatives.

Following are survey results based to six markets: all Ketchikan visitors, overnight visitors who traveled to and from Alaska by air, cruise passengers, overnight visitors who traveled to and/or from Alaska by highway or ferry, overnight visitors traveling for vacation/pleasure, and overnight visitors traveling for vacation/pleasure from Western U.S. states. Please see the Methodology chapter for additional detail.

Alaska Trip Purpose and Packages

- Nearly all Ketchikan visitors (97 percent) were traveling for vacation/pleasure, with only 2 percent traveling to visit friends/relatives and 1 percent traveling for business-related purposes.
- Among air visitors, 50 percent were traveling for vacation/pleasure; 33 percent to visit friends/relatives; and 17 percent for business-related reasons.
- Among ferry visitors, 64 percent were traveling for vacation/pleasure; 26 percent were VFRs; and 9 percent were traveling for business-related reasons.

Table 3. Trip Purpose (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Vacation/pleasure (V/P)	97	50	99	64	100	100
Visiting friends or relatives (VFR)	2	33	<1	26	-	-
Business only	1	12	<1	1	-	-
Business and pleasure	<1	5	<1	8	-	-

- Because of the high proportion of cruise passengers in the overall sample of visitors, nearly all Ketchikan visitors were “package” visitors – meaning, they purchased a multi-day package for their Alaska trip. Note that the package could have occurred anywhere in the state, not only Ketchikan.
- All cruise passengers are assumed to be package visitors. Package visitors represented 18 percent of air visitors, 4 percent of highway/ferry visitors, 28 percent of non-cruise vacation/pleasure visitors, and 26 percent of vacation/pleasure visitors from the Western U.S.
- Nearly all non-cruise package visitors (87 percent) reported purchasing fishing lodge packages. Other subgroups’ sample sizes were too small to break out by package type.

Table 4. Packages (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Purchased multi-day package (including cruise)						
Yes	96	18	100	4	28	26
Package Type (non-cruise only)						
Fishing lodge	87	*	*	*	*	*
Wilderness lodge	4	*	*	*	*	*
Hunting	1	*	*	*	*	*
Adventure tour	<1	*	*	*	*	*
Other	8	*	*	*	*	*

*Sample sizes for sub-groups are too small for analysis.

Length of Stay, Lodging, and Destinations

- Ketchikan visitors reported spending an average of 8.5 nights in Alaska. Highway/ferry visitors reported the longest average stays at 19.3 nights. Air visitors reported an average of 9.1 nights; cruise visitors, 8.4 nights; non-cruise vacation/pleasure visitors, 11.0 nights; and vacation/pleasure visitors from Western U.S., 9.7 nights.
- Visitors who overnighted in Ketchikan reported an average length of stay in the community of 5.8 nights, ranging from 4.7 among non-cruise vacation/pleasure visitors to 6.4 nights among all air visitors.

Table 5. Length of Stay (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
1-3 nights	1	12	<1	6	7	10
4-7 nights	62	54	63	13	49	51
8-14 nights	35	21	35	27	20	21
15-21 nights	2	7	1	22	11	10
22+ nights	1	7	<1	32	12	8
Average # of nights in Alaska	8.5	9.1	8.4	19.3	11.0	9.7
Average # of nights in Ketchikan (base: overnighted)	5.8	6.4	*	6.0	4.7	5.1

- Ketchikan visitors were most likely to have stayed in hotels/motels in Ketchikan, followed by friends/family and lodges. Not surprisingly, highway/ferry visitors were more likely than air visitors to stay in campgrounds/RVs (27 versus 1 percent).

Table 6. Lodging Types Used in Ketchikan (%)
Base: Overnighed in Ketchikan

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Hotel/motel	39	40	*	43	46	40
Friends/family	26	34	*	14	18	18
Lodge	9	12	*	1	17	18
Vacation rental	9	11	*	3	12	12
Campgrounds/RV	5	1	*	27	8	6
Bed & Breakfast	3	3	*	9	4	6
Wilderness camping	1	<1	*	2	-	-
Other	10	4	*	4	4	4

*The sample size of cruise passengers overnighing in Ketchikan was too small for analysis.

- The table on the following page shows where Ketchikan visitors went in Alaska, in addition to Ketchikan. In terms of regions, 33 percent of Ketchikan's visitors traveled to Southcentral, and 20 percent went to the Interior. Just 1 percent visited Southwest, and less than 1 percent visited the Far North.
- Ketchikan cruise visitors followed familiar patterns, with high levels of visitation to Juneau, Skagway, Glacier Bay, and Icy Strait Point. About one-third of cruise passengers traveled to Southcentral (primarily Anchorage and the Kenai Peninsula).
- Air visitors traveled much less widely around the state than either cruise or highway/ferry visitors. The most frequent destinations, in addition to Ketchikan, were Juneau (15 percent), Prince of Wales Island (12 percent), and Anchorage (11 percent).
- Ketchikan highway/ferry visitors' most frequent destinations were Juneau (38 percent), Anchorage (30 percent), and Haines (29 percent).

Table 7. Destinations Visited (Day or Overnight) (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Southeast	100	100	100	100	100	100
Ketchikan	100	100	100	100	100	100
Juneau	96	15	99	38	28	20
Skagway	78	3	82	20	8	6
Glacier Bay Nat'l Park	48	1	50	7	4	3
Hoonah/Icy Strait Point	22	2	23	2	2	1
Sitka	13	7	13	14	13	13
Haines	6	4	5	29	11	6
Prince of Wales Island	1	12	<1	14	14	16
Wrangell	<1	2	<1	8	6	4
Petersburg	<1	3	<1	13	5	2
Gustavus	<1	3	<1	10	8	8
Southcentral	33	12	33	31	20	14
Anchorage	28	11	29	30	19	14
Kenai Peninsula	20	7	20	12	12	8
Talkeetna	8	4	8	16	10	8
Whittier	8	5	8	5	9	7
Palmer/Wasilla	1	3	1	11	4	1
Girdwood/Alyeska	2	1	2	2	2	3
Valdez	1	3	<1	8	6	1
Interior	20	9	20	32	20	14
Denali Nat'l Park	19	8	20	14	17	10
Fairbanks	11	3	11	23	10	8
Southwest	1	-	1	1	<1	<1
Kodiak	1	-	1	1	<1	<1
Far North	<1	-	<1	4	1	1

Activities

- Ketchikan visitors reported a wide variety of activities while in the community. The most common activities were city/sightseeing tours (22 percent), wildlife viewing (12 percent), shows/Alaska entertainment (presumably referring to the lumberjack show; 11 percent), and day cruises (9 percent).
- Not surprisingly, activity participation varied widely by submarket. Cruise passengers were much more likely to participate in city/sightseeing tours and shows/Alaska entertainment. Non-cruise segments were all much more likely to participate in museums, hiking/nature walk, and fishing.

Table 8. Activities in Ketchikan (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
City/sightseeing tours	22	4	23	7	5	4
Culture/history	18	20	18	38	22	23
Native cultural tours/activities	9	4	9	12	5	4
Historical/cultural attractions	7	9	7	19	13	13
Museums	6	13	6	28	16	18
Wildlife viewing	12	21	12	29	19	19
Birdwatching	2	4	2	5	5	4
Shows/Alaska entertainment	11	3	12	7	2	1
Day cruises	9	5	9	5	7	8
Hiking/nature walk	7	24	7	26	19	19
Flightseeing	6	6	6	5	8	8
Fishing	3	43	2	26	52	54
Guided	2	20	2	3	28	27
Unguided	1	25	<1	25	25	30
Salmon bake/crab feed	3	2	3	2	3	4
Zip-line	2	2	2	<1	2	3
ATV/4-wheeling	1	<1	1	1	-	-
Kayaking/canoeing	1	6	1	1	2	2
Camping	<1	2	-	13	4	2

Satisfaction Ratings

- Ketchikan visitors expressed a high degree of satisfaction with their Alaska experience, with 77 percent very satisfied; 21 percent satisfied; and just 1 percent dissatisfied. (Note that the question asked about the overall Alaska experience, not the Ketchikan experience.)
- Non-cruise visitors expressed slightly higher satisfaction than cruise visitors. Very satisfied ratings ranged from 80 percent among highway/ferry visitors, to 88 percent among air visitors, to 91 percent among non-cruise vacation/pleasure visitors, to 92 percent among vacation/pleasure visitors from the Western U.S. This compares with 76 percent among cruise visitors.

Table 9. Satisfaction with Overall Alaska Experience (%)

	Transportation Mode				Non-Cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Very satisfied	77	88	76	80	91	92
Satisfied	21	11	21	19	9	8
Neither/neutral	2	<1	2	<1	1	-
Dissatisfied	1	<1	<1	-	-	-
Very dissatisfied	-	-	-	-	-	-

- Two-thirds of Ketchikan visitors (66 percent) said their Alaska trip was either higher or much higher than their expectations, while 31 percent said it was about what they expected. Just 3 percent said their trip fell below expectations.
- Among subgroups, non-cruise vacation/pleasure visitors were the most likely to say their trip was higher or much higher than expectations (79 percent), while highway/ferry visitors were the least likely (61 percent). Air visitors, cruise visitors, and Western U.S. visitors fell in between at 73 percent, 66 percent, and 78 percent, respectively.

Table 10. Alaska Trip Compared to Expectations (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Much higher than expectations	30	31	30	22	31	34
Higher than expectations	36	42	36	39	48	44
About what you expected	31	26	31	38	21	21
Below expectations	2	-	2	2	1	1
Far below expectations	1	1	1	-	-	-

* Business-only visitors were screened out of this question.

- When asked about value for the money compared to other destinations, Ketchikan visitors were most likely to say that Alaska was “about the same” at 44 percent. Another 44 percent said the value was either better or much better, while 12 percent said it was worse or much worse.
- Air visitors were more likely to give a “much better” rating (32 percent) compared to cruise (17 percent) and highway/ferry (15 percent).

Table 11. Value for the Money Compared to Other Destinations Visited in the Past Five Years (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Much better	18	32	17	15	26	28
Better	26	27	26	29	29	33
About the same	44	34	45	33	29	31
Worse	11	7	11	23	15	8
Much worse	1	-	1	1	<1	-

*Business-only visitors were screened out of this question.

- Ketchikan visitors were highly likely to recommend Alaska to friends/family, with 80 percent very likely and another 17 percent likely. Only 1 percent said they were unlikely.
- Cruise passengers were slightly less likely to recommend Alaska compared to non-cruise visitors, with 80 percent saying they were very likely, compared to between 85 and 92 percent of non-cruise visitors.

Table 12. Likelihood of Recommending Alaska to Friends/Family (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Very likely	80	91	80	85	91	92
Likely	17	8	17	14	9	8
Unlikely	1	<1	1	-	-	-
Very unlikely	<1	<1	<1	<1	-	-
Don't know	1	<1	1	1	<1	-

Previous and Future Alaska Travel

- Seven out of ten Ketchikan visitors (71 percent) were on their first trip to Alaska. Cruise passengers were much more likely to be on their first trip (73 percent) compared with air (33 percent) and highway/ferry visitors (45 percent).
- Among repeat travelers, the average number of previous trips was 2.7.
- One out of five visitors (20 percent) had been on an Alaska cruise before, including 20 percent of cruise passengers, 15 percent of air visitors, and 7 percent of highway/ferry visitors.

Table 13. Previous Alaska Travel (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
First trip to Alaska	71	33	73	45	43	38
Been to Alaska before	29	67	27	55	57	62
Average # of vacation trips (base: repeat travelers)	2.7	4.5	2.4	4.2	5.7	6.7
Been on Alaska cruise before	20	15	20	7	15	14

- Twenty-seven percent of Ketchikan visitors said it was very likely they would return to Alaska in the next five years, while another 20 percent said it was likely. Nearly half (44 percent) said it was unlikely or very unlikely.
- Air visitors were by far the most likely to say they were very likely to return at 80 percent. This compares with 46 percent of highway/ferry and 25 percent of cruise.

Table 14. Likelihood of Returning to Alaska in the Next Five Years (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Very likely	27	80	25	46	67	79
Likely	20	10	20	24	15	13
Unlikely	34	5	35	20	10	7
Very unlikely	10	2	10	8	4	-
Don't know	9	3	9	2	4	1

- Among those very likely to return, Ketchikan visitors were most interested in experiencing fishing (15 percent), wildlife (14 percent), and Northern Lights (11 percent) on their next Alaska trip.
- Air and highway/ferry visitors were much more likely to mention fishing (47 and 37 percent, respectively) when compared with cruise visitors (10 percent). Cruise visitors were much more likely to mention wildlife (15 percent), Northern Lights (12 percent), Denali (11 percent), and flightseeing (11 percent) when compared to non-cruise visitors.

Table 15. Most interested in experiencing on your next Alaska trip (%)
Base: Very likely to return to Alaska within five years

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Fishing	15	47	10	37	65	61
Wildlife	14	3	15	1	2	3
Northern Lights	11	3	12	7	5	6
Denali	10	2	11	5	3	3
Flightseeing	10	4	11	6	2	3
Cruise	8	2	9	-	3	2
Hiking	6	4	6	3	1	1
Glaciers	4	2	4	4	2	3
Visiting friends/family	3	19	1	22	6	8
Camping	2	2	3	1	1	1
Other	2	2	2	4	3	2
Don't know	5	3	6	4	1	<1

Trip Planning

Trip Planning Timeline

- Ketchikan visitors made their decision to travel to Alaska an average of 8.7 months ahead of their trip. The most common planning period was January through March (23 percent).
- Cruise visitors reported the longest lead time for their trip decision (8.8 months), while air visitors reported the shortest (6.0 months).
- Visitors booked their major travel arrangements an average of 6.5 months ahead of time, with the most common booking period matching the most common period for trip decision (January through March).
- Cruise visitors reported the longest lead time for trip booking at 6.6 months, while highway/ferry visitors reported the shortest lead time at 3.3 months.

Table 16. Trip Planning by Quarter (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
How far in advance did you decide to come on this trip to Alaska?						
Before July 2015	18	7	18	17	12	8
July-Sept 2015	19	19	19	17	24	22
Oct-Dec 2015	20	12	21	11	17	16
Jan-Mar 2016	23	22	23	24	21	23
Apr-Jun 2016	14	30	14	27	19	20
July-Sept 2016	5	10	5	4	8	10
Average # of months	8.7	6.0	8.8	7.5	7.8	7.0
How far in advance did you book your major travel arrangements?						
Before July 2015	9	3	9	1	5	5
July-Sept 2015	15	8	15	1	11	6
Oct-Dec 2015	19	11	19	8	15	13
Jan-Mar 2016	29	24	29	31	25	29
Apr-Jun 2016	21	39	20	48	34	34
July-Sept 2016	8	15	7	10	11	12
Average # of months	6.5	4.1	6.6	3.3	5.2	4.7

Internet Usage and Booking

- Nearly two-thirds of Ketchikan visitors (62 percent) used the internet to plan their trip, including 49 percent who booked at least some component online.
- Internet usage rates were much lower among cruise visitors (61 percent) than among air (85 percent) or highway/ferry visitors (82 percent). Online booking rates were much higher among air visitors (83 percent) than among either cruise (48 percent) or highway/ferry visitors (59 percent).

Table 17. Internet Usage for Trip Planning/Booking (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Used internet	62	85	61	82	84	87
Booked over internet	49	83	48	59	78	81
Did not use internet	35	11	36	17	14	11
Don't know	3	4	3	1	2	2

- Among online bookers, the most common trip components booked online were cruise (34 percent), airfare (34 percent), and tours (19 percent).
- Unsurprisingly, rates differed significantly by transportation market. Air visitors were highly likely to book airfare online; cruise visitors were most likely to book their cruise online; and ferry visitors were highly likely to book ferry tickets online.

Table 18. Trip Components Booked Online, Including via Apps (%)

Base: Booked some portion of trip online

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Cruise	34	-	36	-	-	-
Airfare	34	81	32	18	66	71
Tours	19	8	20	4	13	11
Lodging	13	28	13	33	35	36
Vehicle rental	3	7	3	3	7	8
Overnight packages	2	3	2	-	5	4
Ferry	1	8	<1	52	19	16

Websites/Apps Used for Planning/Booking

The following page shows specific websites used for planning.

- The top websites (or types of websites) were cruise line websites (63 percent), airline websites (42 percent), TripAdvisor (27 percent), and Google (27 percent).
- Air visitors were most likely to use airline websites (86 percent), TripAdvisor (16 percent), and Google (15 percent). Cruise visitors were most likely to use cruise line websites (67 percent), airline websites (40 percent), and TripAdvisor (28 percent). Highway/ferry visitors were most likely to use the AMHS website (79 percent), airline websites (26 percent), and hotel/lodge/RV park websites (23 percent).

Table 19. Websites/Apps Used to Plan (%)
Base: Used the internet to plan or book any portion of Alaska trip

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Cruise line websites	63	2	67	3	3	3
Airline websites	42	86	40	26	73	76
TripAdvisor	27	16	28	18	20	8
Google	27	15	27	21	22	19
Expedia	14	12	14	18	16	10
CruiseCritic.com	12	1	13	-	2	3
Tour company websites	10	7	10	4	12	3
Hotel/lodge/RV park	9	13	8	23	16	10
Travelocity	9	5	9	1	3	2
CVB/Chamber	8	2	9	15	4	1
Facebook	8	4	9	11	5	4
Priceline	6	4	6	3	2	<1
AAA.com	5	2	5	8	2	3
Hotels.com	4	3	5	9	4	3
Yelp	4	3	4	2	2	2
Alaska Marine Highway	4	14	2	79	34	29
Booking.com	3	5	3	13	8	3
Car/RV rental websites	3	5	3	4	4	3
Orbitz	3	1	3	2	2	1
Kayak.com	3	3	3	5	1	<1
Alaska App	2	1	2	5	3	3
VacationsToGo	2	-	2	-	-	-
AirBnB	2	3	2	3	5	5
LonelyPlanet.com	2	4	2	4	7	1
Costco	2	-	2	-	-	-
HotelTonight	1	1	1	-	-	-
Instagram	1	1	1	2	1	1
Hotwire	1	2	1	-	2	3
ARR	1	-	1	<1	<1	-
VRBO	1	4	1	<1	4	<1
Hipmunk	1	1	1	2	3	3
Alaska.org	1	-	1	-	-	-
NPS	<1	1	<1	-	1	1
Twitter	<1	-	<1	2	<1	-
CheapOAir	<1	-	<1	-	-	-
ADF&G	<1	1	-	-	1	1
Other	7	2	8	11	4	5

The following page shows specific websites used for booking (the previous table shows planning).

- The top websites used for booking were cruise line websites (51 percent), airline websites (41 percent), Expedia (8 percent).

- Air visitors' top booking sites were airline websites (85 percent), hotel/lodge/RV park (12 percent), and Alaska Marine Highway (10 percent). Cruise visitors' top booking sites were cruise line websites (54 percent), airline websites (39 percent), and Expedia (8 percent). Highway/ferry visitors' top sites were AMHS (64 percent), airline websites (27 percent), and hotel/lodge/RV park (17 percent).

Table 20. Websites/Apps Used to Book (%)
Base: Used the internet to plan or book any portion of Alaska trip

	All Visitors	Transportation Mode			Non-cruise	
		Air	Cruise	Hwy/Ferry	V/P	West US
Cruise line websites	51	-	54	-	-	-
Airline websites	41	85	39	27	73	79
Expedia	8	6	8	11	6	3
Hotel/lodge/RV park	7	12	6	17	13	9
Tour company websites	6	7	6	<1	11	4
Trip Advisor	3	3	3	4	3	-
Booking.com	2	5	2	7	8	3
VacationsToGo	2	-	2	-	-	-
Car/RV rental websites	2	5	2	4	4	3
Travelocity	2	2	2	-	1	1
Hotels.com	2	1	2	10	2	4
AAA.com	2	-	2	8	-	-
Google	2	1	2	1	2	3
Alaska Marine Highway	1	10	<1	64	24	22
Costco	1	-	2	-	-	-
CruiseCritic.com	1	-	1	-	-	-
Kayak.com	1	2	1	1	<1	-
Priceline	1	1	1	<1	<1	<1
Hotwire	1	2	1	-	2	3
Orbitz	1	1	1	-	1	1
ARR	<1	-	<1	1	<1	<1
AirBnB	<1	3	<1	1	5	5
Facebook	<1	-	<1	-	-	-
VRBO	<1	3	<1	-	3	-
CVB/Visitors Bureau	<1	<1	<1	3	1	<1
LonelyPlanet.com	<1	<1	<1	1	1	-
HotelTonight	<1	<1	<1	-	-	-
Hipmunk	<1	-	<1	2	<1	-
NPS	<1	1	<1	-	1	1
CheapOAir	<1	-	<1	-	-	-
Alaska App	<1	1	<1	2	1	1
Yelp	<1	1	-	-	1	1
ADF&G	<1	1	-	-	1	1
Instagram	<1	-	-	1	<1	-
Other	4	2	4	3	2	2

Travel Agent Usage

- About half of Ketchikan visitors (52 percent) booked at least some portion of their trip through a travel agent. Rates were much higher among cruise passengers (54 percent) than among air (7 percent) or highway/ferry visitors (9 percent).
- The most common trip components booked through a travel agent were cruise (91 percent), airfare (60 percent), and tours (42 percent).

Table 21. Travel Agent Usage for Trip Booking (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Booked through travel agent	52	7	54	9	8	5
Cruise	91	*	92	*	*	*
Airfare	60	*	60	*	*	*
Tours	42	*	42	*	*	*
Lodging	32	*	32	*	*	*
Overnight packages	10	*	10	*	*	*
Vehicle rental	1	*	1	*	*	*
Ferry	<1	*	<1	*	*	*

* Sample size too small for analysis.

Usage of State of Alaska Information Sources

- Seventeen percent of Ketchikan visitors reported visiting travelalaska.com, with highway/ferry visitors reporting the highest rate of usage (42 percent), and air visitors reporting the lowest (16 percent).
- Eleven percent of visitors recalled receiving the Official Vacation Planner, ranging from 11 percent among air and cruise visitors to 24 percent among highway/ferry visitors.

Table 22. Usage of State of Alaska Information Sources (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Did you visit the official State of Alaska travel website travelalaska.com?						
Yes	17	16	17	42	23	20
No	78	74	78	52	67	69
Don't know	5	8	5	4	8	11
Did you receive the State of Alaska Official Vacation Planner?						
Yes	11	11	11	24	17	10
No	83	84	84	74	78	85
Don't know	5	3	5	2	4	4

Usage of Other Information Sources

After being asked about online sources, travel agents, and State of Alaska sources, respondents were asked about additional sources used in planning their Alaska trip.

- The most popular sources of additional information were friends/family (50 percent), cruise line (36 percent), prior experience (17 percent), brochures (13 percent), and AAA (10 percent). All other sources were used by less than 10 percent of the overall visitor market.
- All three transportation markets were most likely to cite friends/family, but at very different rates (72 percent for air, 59 percent for highway/ferry, and 49 percent for cruise). In general, highway/ferry visitors cited the highest number of sources, and air visitors mentioned the fewest number of sources.
- Air visitors were most likely to cite friends/family (72 percent) and prior experience (50 percent). Cruise visitors were most likely to mention friends/family (49 percent), cruise line (38 percent), and prior experience (16 percent). Highway/ferry visitors were most likely to cite friends/family (59 percent), prior experience (44 percent), and brochures (26 percent).

Table 23. Usage of Other Information Sources (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Friends/family	50	72	49	59	59	57
Cruise line	36	-	38	1	<1	<1
Prior experience	17	50	16	44	44	52
Brochures (total)	13	9	13	26	14	13
Brochures	12	3	12	16	7	7
Community brochures	1	4	1	1	3	3
Ferry brochure/schedule	1	4	1	13	7	7
AAA	10	2	10	10	4	5
Tour company	6	<1	6	1	1	1
Other travel guide/book	5	2	5	19	8	5
Television	5	2	5	2	1	-3
Magazine	4	3	4	11	4	2
Library	3	1	3	1	<1	<1
Club/organization/church	3	2	3	1	1	-
Convention & Visitor Bureau(s)	2	1	2	2	1	1
Newspaper	2	1	2	6	1	<1
Hotel/lodge	2	10	2	3	13	16
Milepost	1	3	1	33	11	7
North to Alaska Guide	1	1	1	7	4	1
Travel/recreation exhibitions	1	-	1	1	<1	-

Demographics

Origin

- Ketchikan's visitors are most likely to be from Western U.S. states (32 percent), followed by the South (23 percent), Midwest (15 percent), and East (11 percent). Nine percent are from Canada, and 10 percent are from other international countries, most commonly Australia/New Zealand (4 percent). The most common states of origin were California (13 percent), Washington (7 percent), and Texas (6 percent).
- Air visitors showed the highest rates of Western U.S. origin (73 percent), compared with cruise (30 percent) and highway/ferry visitors (59 percent). Cruise visitors were more likely to be from the South (24 percent) and the Midwest (15 percent) when compared with non-cruise visitors. Highway/ferry visitors showed higher rates of international origin (13 percent) than cruise (10 percent) and air (3 percent).

Table 24. Top Countries/States of Origin (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
United States	81	96	80	84	83	100
Western US	32	73	30	59	66	100
California	13	13	13	4	15	23
Washington	7	33	6	15	24	36
Arizona	3	3	3	1	4	6
Oregon	2	6	2	15	3	5
Nevada	2	3	2	2	4	7
Colorado	2	4	2	8	4	6
Southern US	23	12	24	10	12	-
Texas	6	2	6	3	2	-
Florida	5	4	5	3	4	-
Tennessee	2	1	2	-	-	-
Midwestern US	15	8	15	7	10	-
Ohio	3	2	3	<1	2	-
Illinois	2	1	2	<1	1	-
Minnesota	2	2	2	3	2	-
Michigan	2	1	2	2	1	-
Eastern US	11	3	11	2	3	-
New York	3	<1	3	<1	<1	-
Pennsylvania	2	1	2	2	2	-
New Jersey	2	1	2	-	1	-
Canada	9	1	10	10	2	-
British Columbia	5	1	5	4	<1	-
Ontario	2	-	2	2	1	-
International	10	3	10	13	7	-
Australia/New Zealand	4	1	4	1	3	-
Europe	3	1	3	10	4	-
Asia	1	-	1	-	-	-
Latin America	1	1	1	1	1	-

Party and Group Size

- Ketchikan visitors reported an average party size of 2.5 people (meaning the number of people sharing expenses). The most popular party size was two, representing 64 percent of visitors.
- Party size was higher among cruise visitors (2.6 people) than among air and highway/ferry visitors (1.9 people).
- Visitors reported an average group size of 5.0 people. (This is the number of people traveling together, not necessarily sharing expenses.). Group size was much higher among cruise passengers (5.1 people) than among air visitors (2.9 people) or ferry visitors (2.2 people).

Table 25. Party and Group Size (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Party Size						
1	8	44	7	26	32	36
2	64	38	65	62	50	44
3	8	6	8	8	4	4
4	11	6	11	3	7	6
5+	9	6	9	2	7	10
Average party size	2.5	1.9	2.6	1.9	2.1	2.1
Group Size						
1	5	31	4	20	16	15
2	47	33	48	60	42	36
3	7	9	7	11	9	12
4	16	11	16	5	12	13
5	4	6	4	1	7	8
6-10	13	9	13	3	12	13
11+	9	3	9	<1	2	2
Average group size	5.0	2.9	5.1	2.2	3.1	3.3

Gender and Age

- Ketchikan visitors were slightly more likely to be female (55 percent) than male (45 percent). (These figures reflect the entire traveling party, not just the respondent.) Cruise visitors were more likely to be female at 56 percent, while air and highway/ferry visitors were more likely to be male (56 and 53 percent, respectively). Non-cruise vacation/pleasure and Western U.S. vacation/pleasure visitors had a higher share of males (60 and 62 percent, respectively).
- Ketchikan visitors reported an average age of 57 years old. (This includes all party members, not just the respondent.) Average ages varied little by submarket, ranging from 53 years old among air visitors to 59 years old among highway/ferry visitors. The most common age ranges were 65 and over (33 percent), and 55 to 64 (26 percent). Cruise visitors were more likely to have party members under 18 (10 percent).

Table 26. Gender and Age (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Gender						
Male	45	56	44	53	60	62
Female	55	44	56	47	40	38
Age						
Under 18	10	7	10	5	5	6
18 to 24	3	5	3	2	4	3
25 to 34	5	8	5	6	6	6
35 to 44	9	11	9	7	10	9
45 to 54	14	18	14	12	17	20
55 to 64	26	24	26	26	26	26
65+	33	26	33	42	33	30
Average age	57 years	53 years	57 years	59 years	57 years	56 years

Household Characteristics

- One out of five Ketchikan visitors (22 percent) reported children living in their household. Highway/ferry visitors were slightly less likely to fall into this category (18 percent).
- One-half of visitors (51 percent) said they were retired or semi-retired. Highway/ferry visitors were the most likely to be retired (64 percent), followed by cruise visitors (52 percent), and air visitors (41 percent).

Table 27. Household Characteristics (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Children living in household	22	24	22	18	21	18
Retired or semi-retired	51	41	52	64	55	52

- Ketchikan visitors reported an average household income of \$116,000. Cruise and air visitors' average income were similar at \$116,000 and \$117,000; highway/ferry visitors' average was slightly lower at \$93,000.

Table 28. Household Income (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Less than \$25,000	2	3	2	1	2	2
\$25,000 to \$50,000	7	8	7	9	9	8
\$50,000 to \$75,000	11	11	10	21	13	11
\$75,000 to \$100,000	14	12	14	19	12	12
\$100,000 to \$125,000	11	11	11	16	12	12
\$125,000 to \$150,000	9	10	9	8	9	10
\$150,000 to \$200,000	7	8	7	3	5	4
Over \$200,00	9	10	9	3	12	12
Refused	29	28	29	19	27	30
Average income	\$116,000	\$117,000	\$116,000	\$93,000	\$117,000	\$119,000

- Two-thirds of Ketchikan visitors (64 percent) reported at least a college education. College degree rates were similar across the submarkets: 62 percent among air visitors, 64 percent among cruise visitors, 58 percent among highway/ferry visitors, 65 percent among non-cruise vacation/pleasure visitors, and 63 percent among non-cruise Western U.S. visitors.

Table 29. Education (%)

	Transportation Mode				Non-cruise	
	All Visitors	Air	Cruise	Hwy/Ferry	V/P	West US
Some high school	1	<1	1	3	1	1
High school diploma/GED	10	9	10	11	9	7
Associate/technical degree	8	7	8	6	7	10
Some college	17	22	17	21	17	20
Graduated from college	38	39	38	35	41	36
Master's/Doctorate	26	23	26	23	24	27

Visitor Spending

- Air visitors spent an average of \$872 per person in Ketchikan. Their spending was largely concentrated on lodging (\$207), food/beverage (\$167), and “other” (\$281); the other category includes lodge packages.
- Cruise passengers’ spending was concentrated in gifts/souvenirs/clothing (\$87) and tours/activities/entertainment (\$60).
- Highway/ferry visitors spent an average of \$580 per person, with spending largely occurring in the lodging (\$187) and food/beverage (\$181) categories.
- Non-cruise, vacation/pleasure visitors spent the most of all sub-markets at \$1,055 per person, with spending particularly high in the “other” category (\$425), implying significant package lodge purchases.
- A supplemental analysis of spending by non-cruise visitors shows that vacation/pleasure visitors spent much more, on average, than those visiting friends and relatives. Vacation/pleasure air visitors spent an average of \$1,424 in Ketchikan, and vacation/pleasure highway/ferry visitors spent an average of \$1,397. This compares with \$490 among non-cruise visitors traveling for the purposes of visiting friends/relatives.
- It should be noted that all non-cruise sub-markets include only overnight visitors. Taking day visitors into account, average spending by transportation market decreases to \$657 among air visitors and \$425 among highway/ferry visitors. For purposes of economic impact, average spending among all visitors (not just overnight visitors) was used for both traffic and spending.

Table 30. Visitor Expenditures in Ketchikan, Per Person Per Trip

	Transportation Mode			Non-cruise	
	Air	Cruise	Hwy/Ferry	V/P	West US
Lodging	\$ 207	\$ 0	\$ 187	\$ 194	\$ 165
Tours/activities/entertainment	\$ 63	\$ 60	\$ 72	\$ 99	\$ 85
Gifts/souvenirs/clothing	\$ 92	\$ 87	\$ 55	\$ 111	\$ 140
Food/beverage	\$ 167	\$ 10	\$ 181	\$ 158	\$ 160
Rental cars/fuel/transportation	\$ 62	\$ 1	\$ 58	\$ 68	\$ 70
Other	\$ 281	\$ 0	\$ 27	\$ 425	\$ 254
Total	\$ 872	\$ 158	\$ 580	\$ 1,055	\$ 874

Table 31. Visitor Expenditures in Ketchikan, Per person Per Trip: Selected Subgroups

	Non-cruise		
	V/P Air	V/P Hwy/ferry	VFR
Lodging	\$ 215	\$ 470	\$ 103
Tours	\$ 121	\$ 196	\$ 47
Gifts	\$ 138	\$ 107	\$ 78
Food	\$ 186	\$ 331	\$ 168
Transportation	\$ 101	\$ 154	\$ 42
Other	\$ 663	\$ 139	\$ 52
Total	\$ 1,424	\$ 1,397	\$ 490

TRENDS

The last time Ketchikan visitor spending was measured was for a survey conducted of Ketchikan visitors in summer 2011 at the airport, ferry terminal, and cruise ship docks. The methodology for AVSP was different in that it was conducted statewide at various exit points and included business travelers. With these caveats in mind, here is how spending differed between 2011 and 2016.

- The average spending among cruise passengers was about the same between the two years (\$161 in 2011 and \$158 in 2016).
- The average spending among air visitors increased from \$676 in 2011 to \$872 in 2016. The inclusion of business travelers may have influenced this number slightly.
- The average spending among ferry visitors increased from \$401 in 2011 to \$580 in 2016.

Supplemental Data on Usage of KVB Information Sources by Cruise Passengers

A survey of cruise passengers was conducted for Ketchikan Gateway Borough over the same time period as the AVSP: May to September 2016.¹ The survey included 317 randomly selected passengers intercepted on the Ketchikan cruise docks in the two-hour period before sailing. The sample schedule was designed to ensure representativeness by cruise line, sailing direction (northbound versus southbound), and month of travel. The sample size resulted in a maximum margin of error of ± 5.5 percent at the 95 percent confidence level. Following are excerpts from the report that address planning sources. Because AVSP data is collected at a statewide level, this data is particularly useful in that it asks about specific Ketchikan information sources. Also, AVSP focuses more on planning sources used *before* the trip, while this survey asked about sources used *during* their trip.

Visitor Information Center Use

- More than half (56 percent) of respondents visited one of the Visitor Information Centers. (The survey did not differentiate between Ketchikan's two Visitor Information Centers.)
- The visitor center was used most commonly for gathering information (66 percent) and restrooms (59 percent). Other usages included directions (30 percent), map (14 percent), tour booking (11 percent), and ATM (5 percent).

Table 32. Did you visit the Visitor Information Center today?

	% of Total n=317
Yes	56
No	44
What did you do at the center? (Base: Visited the Visitor Information Center) Multiple responses allowed.	
	n=177
Got information	66
Restrooms	59
Got directions	30
Got a map	14
Booked a tour	11
ATM	5
Other	3
Don't know	3

¹ *Ketchikan Cruise Industry Surveys*, prepared for Ketchikan Gateway Borough for McDowell Group, November 2016.

Ketchikan Arrival Guide and Trip Planner Use

- When asking respondents whether they had used the Ketchikan Arrival Guide, surveyors showed a copy of the Guide. Approximately one-third of respondents (29 percent) used the Ketchikan Arrival Guide.
- Of those who used it, 60 percent felt it was very helpful, and 25 percent felt it was somewhat helpful; no respondents said it was not helpful.
- Seven percent of respondents said they used the Ketchikan Trip Planner (again, a copy of the Planner was shown). The remainder did not use it (88 percent) or were not aware if they used it (6 percent).
- Of the 21 respondents who used the Trip Planner, 33 percent found it very helpful, 48 percent found it somewhat helpful, and 19 percent did not know. No respondents said it was not helpful.

Table 33. Did you use the Ketchikan Arrival Guide/Ketchikan Trip Planner?

% of Total n=317	Arrival Guide	Trip Planner
Yes	29	7
No	69	88
Don't know	3	6
Was the Guide/Planner very helpful, somewhat helpful, or not helpful in planning your Ketchikan visit? <i>(Base: Used the Guide/Planner)</i>	n=91	n=21
Very helpful	60	33
Somewhat helpful	25	48
Not helpful	--	--
Don't know	14	19

Note: Columns may not add to 100 percent due to rounding.

Videos about Ketchikan

- Passengers were asked to recall if they had seen any videos about Ketchikan, where they watched the videos, and the themes of the videos. Over half of respondents (56 percent) had seen videos about Ketchikan.
- Nearly two-thirds (62 percent) of those who watched a video did so in their cabin onboard the ship. One-quarter of the respondents watched videos online, and another 19 percent saw a video during their visit to Ketchikan.
- In terms of video topics, the categories with the highest amount of views were Ketchikan history (46 percent), fishing (31 percent), local art and culture (31 percent), and bush pilots (28 percent). One-fifth of respondents (19 percent) weren't sure of the topic.

Table 34. Do you remember watching any videos about Ketchikan, either before your trip, onboard the ship, or while you were here?

	% of Total n=317
Yes	56
No	42
Don't know	1
Where did you watch the videos? (Base: Watched videos about Ketchikan) Multiple responses allowed.	
	n=179
In your cabin	62
Online	25
In Ketchikan	19
Ship theater	7
Other	1
Don't know	1
Which videos do you remember watching? (Base: Watched videos about Ketchikan) Multiple responses allowed.	
	n=179
Ketchikan history	46
Fishing	31
Local art and culture	31
Bush pilots	28
Native Alaskan art	26
Timber harvesting	21
Don't know	19

Note: Columns may not add to 100% due to rounding.

For additional results from the separate survey of cruise passengers (as well as crew members) conducted by McDowell Group for the Borough, please refer to the report *Ketchikan Cruise Industry Surveys*, November 2016.

Economic Impact Analysis

Spending in Ketchikan by visitors and by the businesses that serve those visitors creates jobs, income, and secondary spending throughout the local economy. Visitor spending creates jobs and payroll with tour companies, hotels and lodges, retail establishments, transportation providers, and a range of other business. Visitor industry businesses and their employees in turn re-spend a portion of that money with other borough businesses (some is spent outside the borough), creating additional economic impacts.

This chapter describes the borough-wide employment and labor income effects of visitor industry-related spending in summer 2017. The analysis includes direct employment and labor income, as well as indirect and induced employment and labor income (the “multiplier effects”).

Direct Spending and Impacts

Visitor Spending

Visitors’ direct economic impacts include the jobs and income created by visitor spending on all goods and services purchased while in Ketchikan.

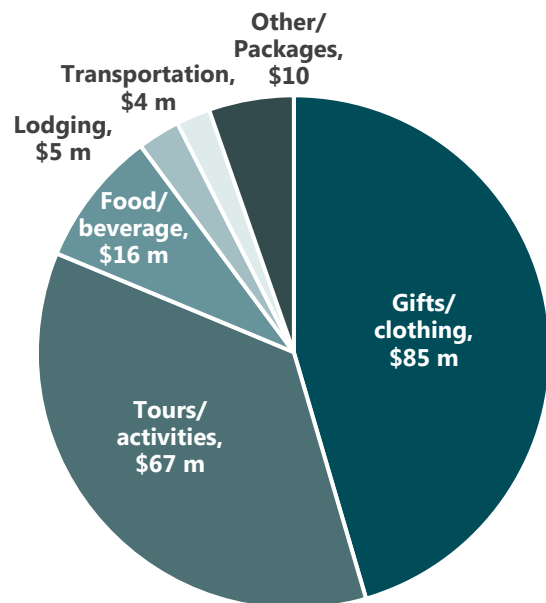
Direct visitor spending totaled an estimated \$187 million in the five-month study period. Gifts, souvenirs, and clothing accounted for nearly one-half (45 percent) of all spending at \$85 million; tours/activities represented one-third (36 percent) at \$67 million; food/beverage represented 9 percent (\$16 million); lodging represented 3 percent (\$5 million); transportation represented 2 percent (\$4 million), and other/packages represented 5 percent (\$10 million).

These figures include tour commissions that accrue directly to cruise lines; these were removed for purposes of economic impact analysis.

Cruise Line Spending

Cruise lines represent an additional source of outside dollars being spent in Ketchikan on behalf of the visitor industry. They make direct purchases from a variety of businesses including food/beverage vendors, transportation service providers, medical providers, and business supply companies, for example. A significant amount of their spending is attributable to moorage/dockage. Cruise lines also pay tour vendors on behalf of their passengers; however, these payments have been excluded because they are included in passenger spending estimates. Cruise lines spent an estimated \$29 million on goods and services in Ketchikan in 2017.

Chart 2. Total Visitor Spending in Ketchikan, By Sector, Summer 2017



**TOTAL VISITOR SPENDING:
\$187 million**

Crew Member Spending

Cruise ships brought an estimated 27,000 crew members to Ketchikan in 2017. A 2016 survey of crew members for the Ketchikan Borough showed that these visitors make significant purchases while in the community, with most of the spending at grocery stores, pharmacies, and larger stores like Wal-Mart. Average spending reported by crew members for the entire season was \$430. Based on industry interviews, a “disembarkation rate” was applied to the crew estimate to account for those employees that do not get a chance to disembark over the course of the season. In total it is estimated that crew members spent \$7 million in Ketchikan.

Total Visitor Industry Spending

Adding together all forms of direct spending, industry spending totaled \$223 million in summer 2017. Visitor purchases accounted for the vast majority (84 percent) of this total, while cruise lines represented 13 percent, and crew represented 3 percent. (For purposes of economic impact visitor spending was adjusted to account for commissions paid directly to cruise lines.)

Direct Employment Impacts

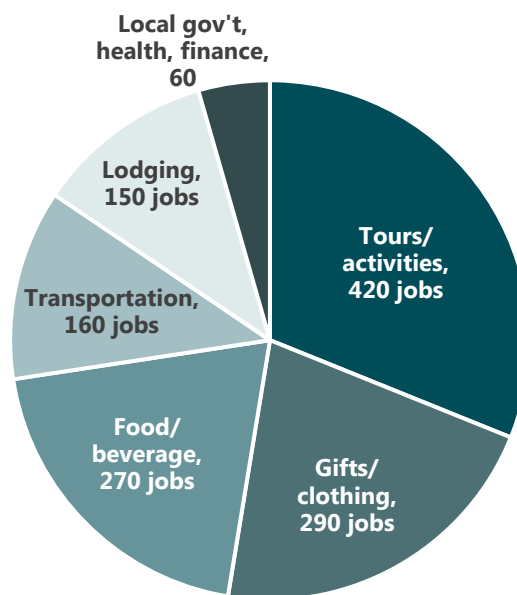
Visitor spending directly generated 1,350 full- and part-time jobs in the borough, and \$57 million in labor income, based on McDowell Group’s economic impact modeling. Employment by sector is distributed similarly to passenger spending, though economic impact varies with the type of spending. For example, spending on service has a greater employment and wage impact than retail spending.

Tours/activities/entertainment accounted for 31 percent of employment at 420 jobs; gifts/souvenirs/clothing accounted for 21 percent at 290 jobs; food/beverage accounted for 20 percent at 270 jobs; transportation/rental cars/fuel accounted for 12 percent at 160 jobs; lodging accounted for 11 percent at 150 jobs; and local government/health care/finance accounted for 4 percent at 60 jobs.

Table 35. Direct Visitor Industry Spending, Summer 2017

	Spending
Visitors	\$187 million
Cruise lines	\$29 million
Crew members	\$7 million
Total Spending	\$223 million

Chart 3. Direct Employment Resulting from Visitor Spending, By Sector, Summer 2017

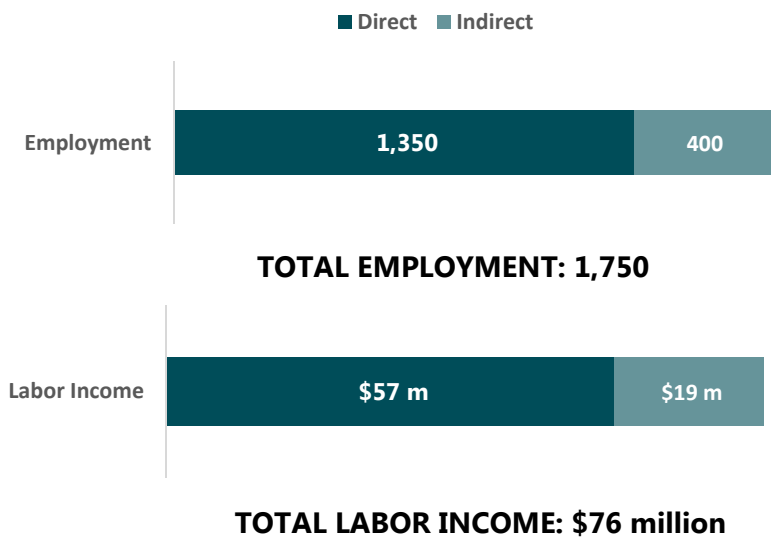


TOTAL DIRECT EMPLOYMENT:
1,350 jobs
TOTAL DIRECT LABOR INCOME:
\$57 million

Total Economic Impacts

Direct employment and labor income estimates do not include multiplier effects, i.e., those jobs and income created in Ketchikan as the visitor dollar is re-spent by visitor industry businesses and their employees. This secondary spending resulted in an estimated 400 jobs and \$19 million in labor income during the summer 2017 study period. Adding secondary impacts to the initial direct impacts of 1,350 jobs and \$57 million in labor income indicates total direct, indirect and induced impacts of 1,750 jobs and \$76 million in labor income.

Chart 4. Direct, Indirect, and Total Employment and Labor Income Resulting from Visitor Industry in Ketchikan, Summer 2017



This estimate is a tally of the total number of full- and part-time jobs linked to non-resident visitor travel to Ketchikan. It includes annual average wage and salary employment, and total proprietors’ employment (the total number of sole proprietorships or partnerships active at any time during the year).

Role in the Ketchikan Economy

The Bureau of Economic Analysis estimated total Ketchikan Borough employment at 10,265 in 2016. Based on the estimate of 1,750 total (direct and indirect) jobs resulting from visitor spending in summer 2017, visitor spending-related employment represented 17 percent of Borough-wide employment. In terms of labor income, visitor spending-related labor income represented 14 percent (\$76 million) of total labor income reported in 2016 (\$526 million). (Visitor industry employment typically represents a greater share than labor income due to lower-than-average wages in this sector.)

The graphic on the following page demonstrates the way visitor spending filters through the local economy (using a gift shop as an example), creating jobs and income in nearly every sector of the economy.

“Alaska Treasure” Gift Shop



Trends in Impacts

This is the third study of Ketchikan's visitor industry impacts; the previous study periods were summers 2006 and 2012. The charts on this page show how visitation and impacts of the industry have grown over the 12-year period.

Visitor volume grew from 830,800 in 2006, up 13 percent to 935,900 in 2012, and up another 13 percent to 1,059,200 in 2017, for a total increase of 27 percent between 2006 and 2017.

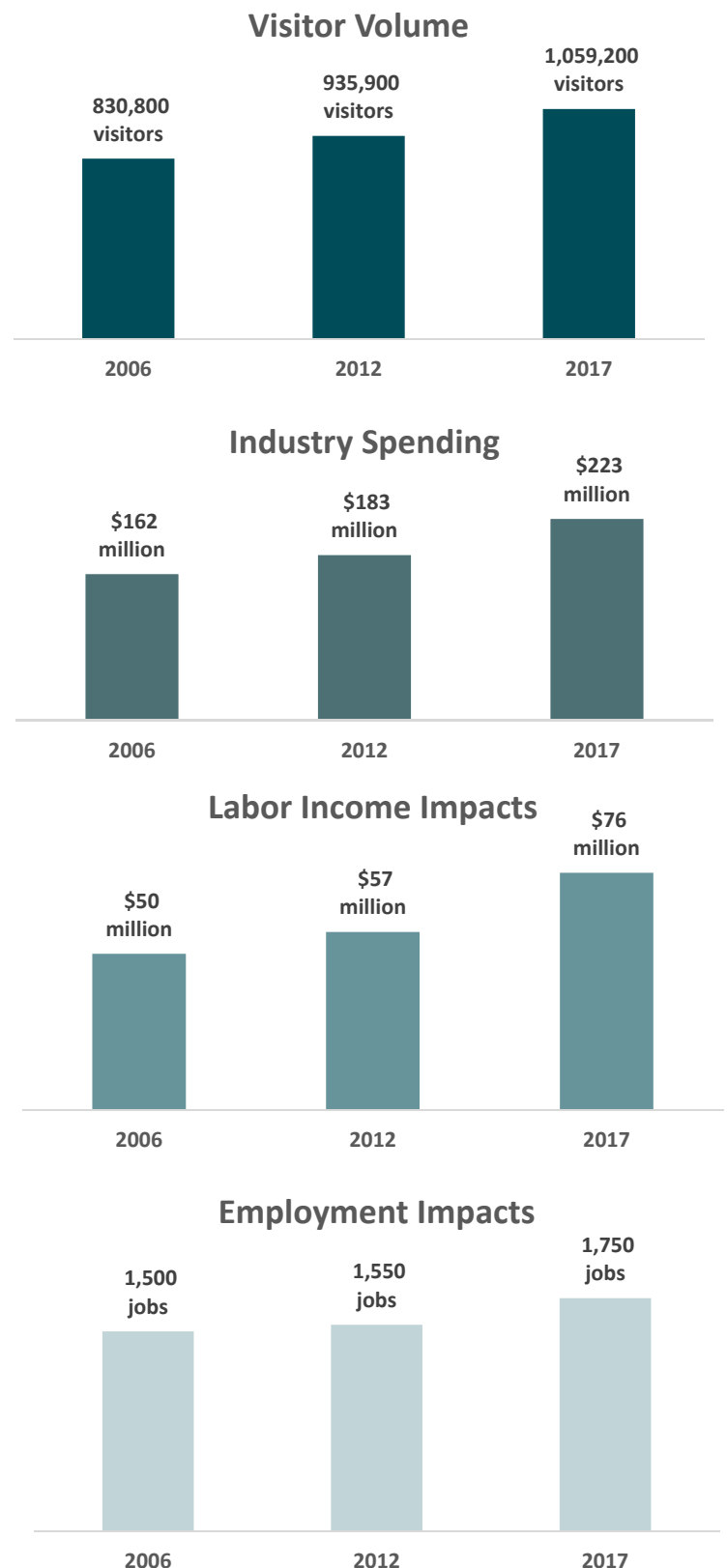
Visitor industry spending increased by 13 percent between 2006 and 2012 (from \$162 million to \$183 million), then by another 22 percent between 2012 and 2017, for a total increase of 38 percent between 2006 and 2017. These percentages reflect "nominal" values; that is, not adjusted for inflation. After adjusting for inflation, industry spending increased by 12 percent between 2006 and 2017.

Labor income increased by 14 percent between 2006 and 2012 (from \$50 million to \$57 million), then by another 33 percent between 2012 and 2017 (from \$57 million to \$76 million) in nominal terms. After adjusting for inflation, labor income actually increased by 23 percent between 2006 and 2017.

Employment was fairly consistent between 2006 and 2012, then increased by 13 percent between 2012 and 2017, for a total increase of 17 percent between 2006 and 2017.

Increases in both visitor and industry spending are largely attributable to increases in visitor volume over the study periods. Per person spending also increased for air and ferry visitors.

Chart 5. Trends in Ketchikan Visitor Impacts, 2006, 2012, 2017



Municipal Revenues

The visitor industry generates significant revenues to the Ketchikan Borough and City of Ketchikan, in the form of dockage/moorage, CPV taxes, sales taxes, and bed taxes. Note that employment and labor income impacts from these taxes and revenues are captured in the previous section as part of the visitor industry spending analysis. (Although property taxes represent an additional revenue source related to the visitor industry, they are difficult to estimate because many visitor industry-related properties serve other markets, and many businesses use names other than their storefront names for tax purposes.)

Dockage/Moorage Revenues

The City of Ketchikan collected \$9.0 million in port-related fees from cruise lines in 2017. Most of this amount is attributable to the “wharfage” fee which generated \$6.9 million; other revenues are attributable to transient docking fees (\$1.1 million), additional docking fees (\$0.8 million), and water services (\$0.2 million).

Table 36. Cruise Line Payments to City of Ketchikan for Port Services, Summer 2017

	Revenues
Passenger wharfage fee	\$6.9 million
Transient docking fees	\$1.1 million
Additional docking fees	\$0.8 million
Water services	\$0.2 million
Total	\$9.0 million

Source: City of Ketchikan.

CPV Tax Revenues

The City of Ketchikan and Ketchikan Borough each received \$2.2 million in 2017 from the Commercial Passenger Vessel Tax (CPV) from the State of Alaska. (The CPV is administered by the State of Alaska; a portion accrues to municipal governments of cruise ports.)

The table below shows CPV revenues to the Borough and City over the duration of the program, which totals nearly \$34 million (including \$21.5 million to the Borough and \$12.5 million to the City) between 2007 and 2017.

Table 37. CPV Tax Payments to City and Borough, 2007-2017

	Ketchikan Gateway Borough	City of Ketchikan	Total
FY 2007	\$203,810	-	\$203,810
FY 2008	2,040,775	-	2,040,775
FY 2009	2,326,147	-	2,326,147
FY 2010	2,313,793	-	2,313,793
FY 2011	2,088,312	-	2,088,312
FY 2012	1,947,248	\$1,947,248	3,894,496
FY 2013	1,977,770	1,977,770	3,955,540
FY 2014	2,240,210	2,240,210	4,480,420
FY 2015	2,032,375	2,032,375	4,064,750
FY 2016	2,141,633	2,141,633	4,283,266
FY 2017	2,163,570	2,163,570	4,327,140
Total 2008-17	\$21,475,643	\$12,502,806	\$33,978,449

Source: Alaska Department of Revenue Shared Taxes and Fees Annual Reports.

Legislative grants represent an additional source of CPV funds. The City of Ketchikan has received nearly \$23 million since Fiscal Year 2009, used for port infrastructure and passenger services.

Table 38. CPV-Related Legislative Grants

	Project	Amount
FY 2009	Port of Ketchikan Berths I and II replacement project	\$3.0 million
FY 2010	Reconstruction of downtown bridges and trestles	\$5.0 million
FY 2010	Port of Ketchikan Berth I and II replacement	\$3.0 million
FY 2011	Replace cruise ship Berths I and II	\$10.0 million
FY 2014	Ketchikan Promenade	\$1.3 million
Total		\$22.3 million

Source: *Commercial Passenger Vessel Excise Tax: Community Needs, Priorities, Shared Revenue, and Expenditures*, Alaska Department of Commerce, Community, and Economic Development, February 2017

Additional examples of investments made by the City of Ketchikan using CPV revenues, according to General Government Operating and Capital Budget documents, include:

- Emergency repairs to Berth III
- Masterplan for improvements to Berths I and II to accommodate future classes of cruise ships
- Installation of stained glass mosaics on waterfront promenade
- Planning and permitting for removal of rock pinnacle
- Installation of benches and planters on the promenade
- Beginning of uplands planning study to accommodate future increase in cruise ship passengers

The Borough uses CPV revenue primarily for passenger safety and passenger services. Examples of expenditures include the following:

- Upgrades to transit system
- Rain and weather shelters
- Pedestrian safety upgrades
- Emergency services upgrades
- Emergency services response materials and equipment

Sales and Bed Tax Revenues

In FY 2017, City and Borough sales tax revenue totaled \$20.7 million. Ketchikan's visitor industry (including cruise lines, crew members, and out-of-state visitors) contributed an estimated \$5.1 million in sales taxes in summer 2017, representing one-quarter of total tax revenues. This is a conservative estimate. There are also indirect and induced sales tax revenues attributable to the visitor industry. For example, a tour company will make a range of taxable purchases of goods and services in Ketchikan, as will the employees of that tour company.

Combined, the City and Borough collected \$616,313 in bed taxes in 2017. Approximately one-half of these revenues (\$300,000) are attributable to out-of-state visitors in the months of May to September. The remaining revenues resulted from business travel, regional travel, in-state travel, fall/winter/spring travel, and local resident usage.

THE BOAT COMPANY/UNCruise ADVENTURES

April 15, 2021

Chris French, Acting Undersecretary for Natural Resources and Environment
U.S. Department of Agriculture
1400 Independence Avenue, S.W.
Washington, DC 20250
Email: chris.french@usda.gov

Re: Request for USDA to Withdraw Three Pending Old Growth Logging Projects on the Tongass National Forest

Dear Mr. French:

We understand that the Department of Agriculture may be reviewing three large timber sale project proposals on the Tongass National Forest – the Twin Mountain II Timber Sale on Prince of Wales Island, the South Revillagigedo Integrated Resource Project, and the Central Tongass Project – for compliance with new agency priorities related to climate change and biodiversity. We write on behalf of The Boat Company and UnCruise Adventures and urge you to withdraw the projects, which would cut up to 17,000 acres of old-growth forest.

Our companies are part of Southeast Alaska's small cruise vessel fleet - a diverse group of overnight commercial passenger vessels that carry between 6 and 250 passengers and operate along Southeast Alaska marine travel routes adjacent to all three proposed timber project areas. Most small cruise vessel operators have Tongass National Forest special use permits which enable us to provide thousands of visitors with hiking, beach combing, wildlife viewing and other remote recreation experiences. The Boat Company also offers guided sport fishing opportunities. The region's fish and wildlife biodiversity – salmon, iconic forest megafauna such as bears, bald eagles and other species provide unique wildlife viewing opportunities that are a major attraction for our clients. This biodiversity is part of why Southeast Alaska hosts two-thirds of all Alaska visitors each year, making it the most visited region in the state.

President Biden's January 2, 2021 Executive Order directs agencies to "implement a Government-wide approach that ... conserves our lands, waters, and biodiversity."¹ Biodiversity is essential to the variety of ecosystem services provided by the Tongass National Forest, including the cultural services (recreation, aesthetics, and eco-tourism) that attract our clients. Biodiversity is also a buffer against environmental change, such as the warming climate.² We cannot understate the importance of Tongass National Forest biodiversity to our clients and our businesses. We offer wildlife viewing activities nearly every day and work with other operators who focus on wildlife photography.

Withdrawing the three projects would benefit Pacific salmon biodiversity by maintaining habitat that contributes to the recovery of vulnerable salmon populations – an ecosystem service that supports subsistence, sport, and commercial fisheries, benefitting numerous Americans. The Boat Company's fishing guides have decades of experience fishing anadromous salmon streams in central Southeast Alaska. In recent years, we have observed unprecedented drought conditions and exceptionally poor fishing. Our review of the Forest Service's analyses for the three timber projects indicates potential changes to water yield, peak flow volume, and timing of flow delivery, sediment delivery, altered riparian vegetation, herbicide treatments and road stream crossing channel disturbance. There are numerous failed culverts in all three project areas blocking access to upstream spawning habitat.

The availability of spawning salmon is essential to forest biodiversity. Recent declines in salmon abundance have also affected the region's bears. Bears are a top species for wildlife viewing visitors and generate hundreds of jobs and millions of dollars in Alaska and nearby coastal temperate rainforest communities.³ Our onboard naturalists provide visitors with scientific and ecological

information about the Tongass National Forest's black and brown bears and viewing opportunities throughout the region. The agency's responsibility to maintain foraging, denning and other habitat needs for bears is significant for both biodiversity and Southeast Alaska's socio-economic well-being.

Bears are an umbrella species with large area requirements and varied habitat uses, including riparian areas, estuaries, and old-growth forests. For this reason, the health of bear populations is an indicator of overall ecosystem integrity. The main threat to brown and black bear populations in Southeast Alaska is clearcut logging.⁴ Extensive habitat changes in the three project areas have already reduced carrying capacity for bears and likely caused population declines. Forest Service and Alaska Department of Fish and Game biologists have identified serious concerns with long-term decreases in old-growth forest habitat suitability, loss of denning and foraging habitat and susceptibility to human disturbances due to high road densities.⁵ A particular concern is the loss of riparian habitat which has disproportionate and non-linear displacement effects on female bears. All three projects rely on 100' riparian buffers to mitigate impacts to bears even though biologists recommend buffers five times as large for foraging needs and ten times as large where management objectives seek to maintain healthy abundant bear populations are desired for viewing opportunities.

Another major concern with significant implications for biodiversity is that both the Central Tongass and South Revilla projects propose project-specific Forest Plan amendments that would weaken standards and guidelines designed to maintain scenic values. Most of the marine waterways utilized by our vessels are adjacent to areas designated as a "Scenic Viewshed" under the Forest Plan.⁶ Scenic Viewsheds are a specific Forest Plan Land Use Designation (LUD) where timber development activities can occur. However, Forest Plan scenery standards and guidelines limit timber activities in the Scenic Viewshed LUD to selective cuts or small openings.

For this reason, the Tongass National Forest's old-growth habitat conservation strategy relies on the Scenic Viewshed LUD to provide connectivity to conservation LUDs, and particularly the beach and estuary fringe, or beach buffer. There is a prohibition on old-growth logging in the beach and estuary fringe extending 1,000' inland. Many of the reviewers of the conservation strategy preferred a no-cut zone 3,000' inland.⁷ The beach buffer is the most important habitat and main travel corridor for numerous wildlife species, including bears, deer and bald eagles. The limits on clearcutting offered by the scenery standards (specifically, "Scenic Integrity Objectives" or as shown to the right, an "SIO") provides wildlife species with important habitat needed to access the beach buffer.

Specifically, the Forest Service must maintain "high" scenic integrity in the most visible portions of a Scenic Viewshed, meaning that viewers would observe a "natural-appearing landscape."⁸ The Central Tongass and South Revilla projects would reduce scenic integrity to "very low" or even "unacceptably Low" ratings, meaning that landscapes would appear "heavily altered." The reduced scenic values could last between forty years and to a century. Under the proposed actions for the Central Tongass and South Revilla Projects, clearcuts could increase in size to between 50 and 100 acres. The two projects could make nearly 14,000 acres of clearcuts visible from Forest Plan "Visual Priority Routes" where Ranger Districts would otherwise emphasize scenery for private boaters and cruise passengers.⁹



Very Low SIO



High SIO

The sole reason for compromising Scenic Integrity Objectives is a perceived need to improve timber economics through larger clearcut sizes. For our companies, however, this is also a business as well as a biodiversity concern. The Forest Plan FEIS recognizes that:

...demand for scenic quality can best be represented by the increase in tourist-related travel to the Tongass, as well as a heightened awareness and sensitivity of Alaskan residents to scenic resource values. These facts result in a strong indirect connection between scenic resource values and the economy of Southeast Alaska. For example, Southeast Alaska's Inside Passage is advertised and promoted by the Division of Tourism, cruise ship operators, and the Southeast Alaska Tourism Council. Their marketing strategy focuses on the scenery of the Tongass National Forest as a major attraction. *The visitors to Southeast Alaska would, therefore, arrive with expectations and an image of the environment and scenery awaiting them. If current trends continue, demand for viewing scenic landscapes will increase.*

...Lands adjacent to the Alaska Marine Highway, cruise ship routes, flight-seeing routes, high-use recreation areas, and other marine and land-based travel routes will be seen by more people, more frequently, and for greater duration.¹⁰

The three timber sale projects will adversely affect biodiversity and business. Logging and associated industrial activities change the remote and non-industrial character of the Tongass, adversely affect wildlife that depends on these lands and waters, affect our ability to use areas, and potentially affect our ability market and sell Southeast Alaska as an adventure travel destination. We would not take our clients to areas that feature fresh or recent clear cuts or areas with active logging. The sights and sounds associated with those activities are incompatible with what our customers expect and want to see while in the wilds of Southeast Alaska.

Sincerely,



Hunter McIntosh, President

The Boat Company

hunter@theboatcompany.com

Dan Blanchard

CEO/Owner

UnCruise Adventures

danb@uncruise.com

Cc: Robert Bonnie, Deputy Chief of Staff for Policy, U.S. Department of Agriculture,

robert.bonnie@usda.gov

Vicki Christiansen, Chief, U.S. Forest Service, victoria.christiansen@usda.gov

Christine Dawe, Ecosystem Management Coordination, U.S. Forest Service, christine.dawe@usda.gov

David Schmid, Regional Forester, Region 10, U.S. Forest Service, david.schmid@usda.gov

¹ Executive Order 14,008, 86 Fed. Reg. 7619 (Jan. 27, 2021).

² Thompson, I.D., et al. 2011. Forest Biodiversity and the delivery of ecosystem good and services: translating science into policy. *Bioscience*, Vol. 61 No. 12 at 972. December 2011.

³ EcoNorthwest. 2014. The economic importance of Alaska's wildlife in 2011. Final Report to the Alaska Department of Fish and Game, Division of Wildlife Conservation, contract 1HP-12-053. Portland, Oregon; Young, T.B. & J.M. Little. 2019. The economic contribution of bear viewing in south central Alaska. University of Alaska Fairbanks. Center for Responsible Travel. 2014. Economic impact of bear viewing and bear hunting in the Great Bear Rainforest of British Columbia. Washington, D.C.

⁴ Lowell, R. 2013. Unit 3 black bear management report. Chapter 6, Pages 6-1 through 6-26 in P. Harper and L.A. McCarthy, editors. Black bear management report of survey and inventory activities. 1 July 2010-30 June 2013. Alaska Department of Fish and Game. Juneau, Alaska. Lowell, R. 2011. Unit 3 brown bear management report. Pages 19-27 in P. Harper, editor. Brown bear management report of survey and inventory activities. 1 July 2008-30 June 2010. Alaska Department of Fish and Game. Juneau, Alaska.

⁵ USDA Forest Service. 2016. Wrangell Island Project Draft Environmental Impact Statement. U.S. Forest Service, Alaska Region. Tongass National Forest, Wrangell Ranger District. R10-MB-634. May 2016. Pp. 98-100. USDA Forest Service. 2012. Tonka Timber Sale Final Environmental Impact Statement at 3-70-3-72. R10-MB-705c. Tongass National Forest, Petersburg, Alaska. March 2012; *see also* Dungan, J. 2014. Wildlife Resource Report, Mitkof Island EA

⁶ USDA Forest Service. 2016. Land and Resource Management Plan at 3-103. Alaska Region, Tongass National Forest. R-10-MB-769j. December 2016.

⁷ USDA Forest Service. 2008. Tongass Land Management Plan Final Environmental Impact Statement, Appx. D.

⁸ USDA Forest Service. 2016. Land and Resource Management Plan at 3-103. Alaska Region, Tongass National Forest. R-10-MB-769j.

⁹ USDA Forest Service. 2016. Land and Resource Management Plan. Alaska Region, Tongass National Forest at 4-54-4-60 & Appx. F. R-10-MB-769j. December 2016.

¹⁰ USDA Forest Service. 2016. Tongass Land Management Plan Final Environmental Impact Statement at 3-389-3-390.

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Large, climate-sensitive soil carbon stocks mapped with pedology-informed machine learning in the North Pacific coastal temperate rainforest

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Keywords: machine learning, digital soil mapping, coastal temperate rainforest, soil organic carbon, biogeochemistry, soil science

Supplementary material for this article is available [online](#)

Abstract

Accurate soil organic carbon (SOC) maps are needed to predict the terrestrial SOC feedback to climate change, one of the largest remaining uncertainties in Earth system modeling. Over the last decade, global scale models have produced varied predictions of the size and distribution of SOC stocks, ranging from 1000 to >3000 Pg of C within the top 1 m. Regional assessments may help validate or improve global maps because they can examine landscape controls on SOC stocks and offer a tractable means to retain regionally-specific information, such as soil taxonomy, during database creation and modeling. We compile a new transboundary SOC stock database for coastal watersheds of the North Pacific coastal temperate rainforest, using soil classification data to guide gap-filling and machine learning approaches to explore spatial controls on SOC and predict regional stocks. Precipitation and topographic attributes controlling soil wetness were found to be the dominant controls of SOC, underscoring the dependence of C accumulation on high soil moisture. The random forest model predicted stocks of 4.5 Pg C (to 1 m) for the study region, 22% of which was stored in organic soil layers. Calculated stocks of $228 \pm 111 \text{ Mg C ha}^{-1}$ fell within ranges of several past regional studies and indicate 11–33 Pg C may be stored across temperate rainforest soils globally. Predictions compared very favorably to regionalized estimates from two spatially-explicit global products (Pearson's correlation: $\rho = 0.73$ versus 0.34). Notably, SoilGrids 250 m was an outlier for estimates of total SOC, predicting 4-fold higher stocks (18 Pg C) and indicating bias in this global product for the soils of the temperate rainforest. In sum our study demonstrates that CTR ecosystems represent a moisture-dependent hotspot for SOC storage at mid-latitudes.

1. Introduction

Accurate global soil organic carbon (SOC) maps are necessary to validate terrestrial carbon (C) cycle predictions in Earth System Models (Todd-Brown

et al 2013) however current SOC models drawing on international pedon (soil profile) databases (Soil-GRIDs, HWSD, ISCN, etc) display considerable differences (Köchy *et al* 2015, Sanderman *et al* 2017, 2018a). Database construction, including filling data gaps,

account for some of these discrepancies (Tifafi *et al* 2018) while other sources of uncertainty are associated with scaling up spatially from relatively sparse pedon observations ($\sim 1 \text{ m}^2$) to globally gridded products (Todd-Brown *et al* 2013) and the loss of information relevant to SOC storage at intermediate scales (10 m^2 – 1 km^2) such as landscape topography (Mishra and Riley 2015, Siewert 2017). Regional digital soil mapping may help bridge these scale discontinuities and produce finer resolution ($< 100 \text{ m}$) predictions that retain information on the spatial drivers of SOC storage (Minasny *et al* 2013). For example, Sanderman *et al* (2018b) compiled mangrove SOC stock measurements and used them in conjunction with a global SOC map (Hengl *et al* 2017) and maps of environmental covariates to estimate global mangrove SOC at 30 m resolution. The integration of detailed pedological information with machine learning approaches for large-scale spatial predictions may also enable improvements in SOC mapping (Ramcharan *et al* 2017) and regional SOC assessments may help diagnose errors in global products by providing higher resolution information on SOC controls and its distribution.

Regional SOC assessments have, to date, focused on Arctic and boreal permafrost soils (Hugelius *et al* 2013, 2014), while coastal temperate rainforests (CTR) have not received similar attention despite their similarly high SOC storage (Carpenter *et al* 2014). Globally, temperate rainforests contain the highest density aboveground forest C stocks (up to 1500 Mg ha^{-1} , Keith *et al* 2009), and can be found along the coastal margins of North and South America, Japan and Korea, Australasia, and Scandinavia (Alaback 1991). The N. Pacific coastal temperate rainforest (NPCTR) biome is the largest example, and spans 4000 km of the N. American coast from the Russian River in California, to Kodiak Island in the Gulf of Alaska (Della-Sala 2011). Although several studies have produced regional estimates of SOC stocks in Alaska (Leighty *et al* 2006, Johnson *et al* 2011, Mishra and Riley 2012), no studies to date have produced spatially-explicit SOC stock estimates across the transboundary domain of southeast Alaska (SEAK) and coastal British Columbia (BC).

Soils of the NPCTR can store large quantities of SOC, especially in the wet seasonal and perhumid zones (Carpenter *et al* 2014), with stocks $> 300 \text{ Mg ha}^{-1}$ (to 1 m mineral soil depth) frequently observed in SEAK (Johnson *et al* 2011) and stocks of $> 200 \text{ Mg ha}^{-1}$ common in coastal BC (Shaw *et al* 2018). These large SOC stocks have accumulated in distinctive soil conditions across the NPCTR's mosaic of three hydropedologic landscape units (Lin *et al* 2006): (1) upland forest soils on well-drained slopes, (2) forested wetlands, and (3) poor (lowland) fens (Neiland 1971, D'Amore *et al* 2015). Despite their relatively young age (12–14 cal ka BP, Eamer *et al* 2017), elevated C concentrations are

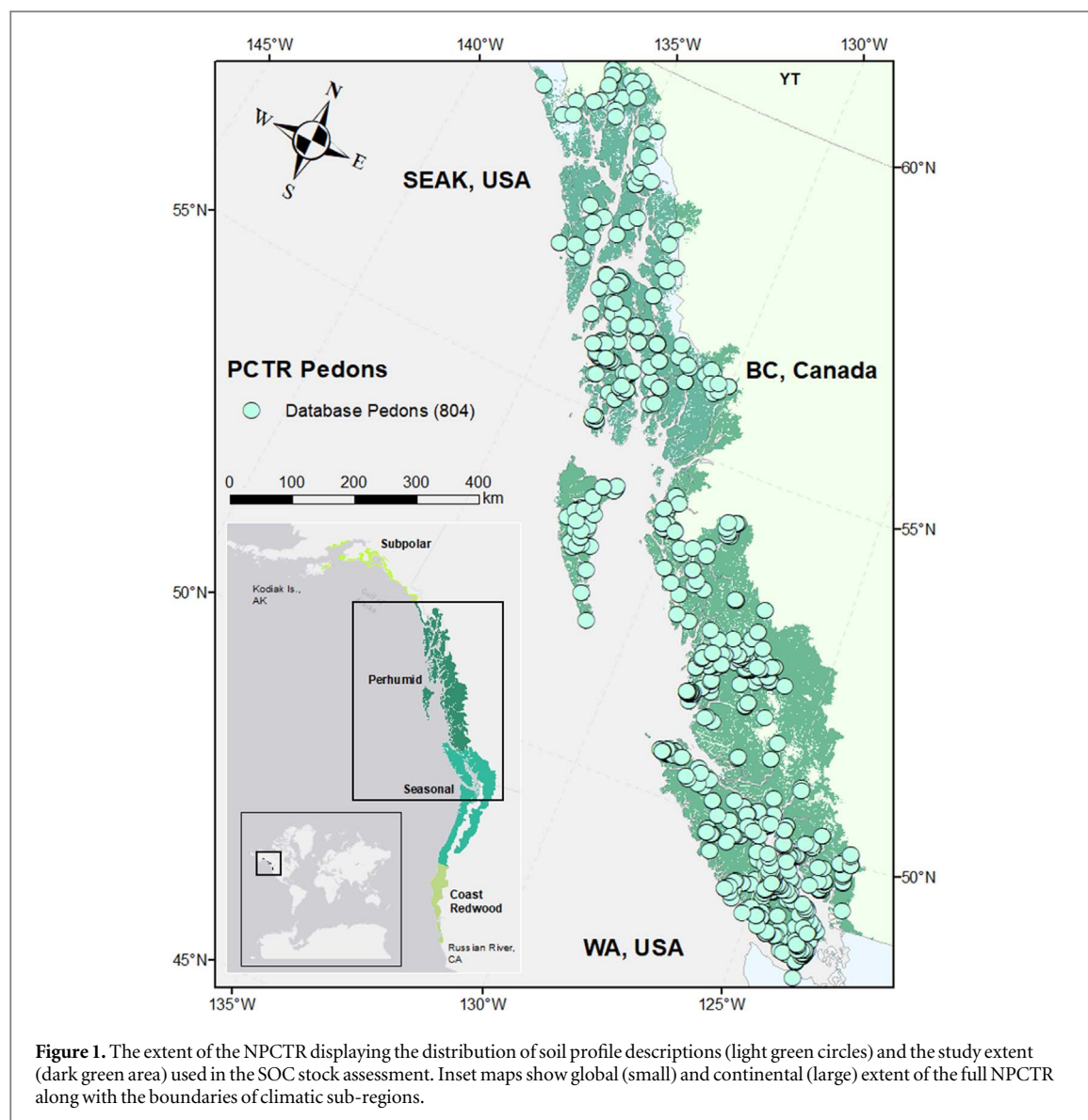
observed in mineral soils that often exceed 1 m in depth (Chandler 1943, Michaelson *et al* 2013) due to a combination of rapid mineral weathering, high primary production and litter inputs, and the translocation of soluble C into deeper horizons (Alaback 1991). In addition to mineral soils, the perhumid NPCTR also exhibits a variety of vertically-accreting organic soils, including deep (3–5 m) peat-forming bogs and fens (Heusser 1952, 1954, Hansen 1955, Ugolini and Mann 1979), and thick ($> 40 \text{ cm}$) forest floor organic horizons that accumulate due to slow decomposition under ubiquitous hydric soil conditions and the rarity of fire (Alaback 1991). In places, deep ($> 40 \text{ cm}$) organic horizons overlay C-rich mineral soils (known as Foli-sols, or folistic horizons) and contribute to the highest C stocks in the NPCTR (D'Amore and Lynn 2002, Fox and Tarnocai 2011, Johnson *et al* 2011, Michaelson *et al* 2013).

Quantifying total SOC storage across the NPCTR and understanding its environmental controls is necessary to predict the region's response to global change, including climate feedbacks. Observational data (Buma and Barrett 2015) and ecosystem C models (Genet *et al* 2018) indicate that the NPCTR is sequestering C. Changes in the amount and form of precipitation and higher temperatures may increase growing season length and productivity (Buma *et al* 2016) however soil warming may lead to more rapid decomposition of soil organic matter (Davidson and Janssens 2006, Fellman *et al* 2017). In the present study we address the need for a unified SOC model for the NPCTR by compiling a new transboundary pedon database across SEAK and coastal BC that retains relevant pedological details. With this database we train a predictive model to estimate total SOC stocks spatially across the region, to enable meaningful comparisons with other regional and global SOC products, and to explore the environmental controls on SOC in the NPCTR.

2. Methods

2.1. Study extent and characteristics

The largest climatic zones within the NPCTR are the seasonal and perhumid forests that form a transboundary extent across SEAK and coastal BC (Alaback 1991). The SOC assessment encompassed all of the perhumid and part of the seasonal zone, spanning 10° of latitude (figure 1). The study perimeter was defined by the outer boundary of rainforest-dominated watersheds mapped using a harmonized transboundary dataset (Gonzalez Arriola *et al* 2018) between the Fraser River in Vancouver, BC and Lituya Bay south of Yakutat, Alaska, excluding the four major river basins (Taku, Stikine, Nass, Skeena) which extend into interior boreal forest and a more continental climate.



Mean annual precipitation across the study domain ranges from 1800 to >3000 mm and mean annual temperatures range from 6 °C to 9 °C, with monthly means of −5 °C in winter in the north (Farr and Hard 1987) and ~15 °C in summer in the south (Alaback 1991). Forest species diversity is relatively low, reflecting a consistent climate and disturbance regime across the study area, and generally dominated by *Picea sitchensis* (Sitka spruce) and *Tsuga heterophylla* (western hemlock) in SEAK (van Hees 2003). In BC, *Tsuga heterophylla* and *Thuja plicata* (western redcedar) become the dominant conifers. *Callitropsis nootkatensis* (yellow cedar) and *Tsuga mertensiana* (mountain hemlock) are found from sea level in the north to high elevations in the south and *Pinus contorta* var. *contorta* (shore pine) is a significant component of bog locations throughout. Geology is varied consisting of granitic, basaltic, and limestone bedrock, the latter of which supports some of the most productive forest, however, much of the surficial geology is

dominated by glacial drift including ablation and compact till, alluvial outwash, and glaciomarine sediments (Nowacki *et al* 2003).

2.2. Transboundary SOC database

We compiled a transboundary database of > 1300 soil profile descriptions (pedons) across SEAK and BC from published and archive data sources. For each pedon we calculated SOC stocks for the top 1 m of mineral soil plus surface organic horizons using data harmonization and gap-filling procedures that are detailed in the supplementary information (supplementary tables 1–5). The database is available online at: <https://datadryad.org/resource/doi:10.5061/dryad.5jff6j1r>. In brief, US soil classification was converted to Canadian where necessary and gaps filled with published values or modeled estimates grouped by soil class, horizon, and lithology. In contrast to some other regional and global C assessments, this approach avoided use of generalized empirical relationships between soil properties and

missing variables, such as between soil C and soil bulk density, or soil C and depth.

2.3. Environmental covariates

Environmental covariates were selected (supplementary table 6) to predict SOC stock due to their relationship with soil forming factors (climate, organisms, relief, parent material, and time; Jenny 1994). Covariate data were extracted from the rasters at the pedon coordinates and appended to the final SOC stocks (in supplementary material) to use in all further analyses. Further details of the 12 selected environmental covariates along with justification for inclusion and pre-processing steps are listed in supplementary table 6. Briefly, only high quality and spatially continuous data products were used. Curating covariates based upon knowledge of regional soil development facilitates clearer interpretation and reduces the risk of autocorrelation between variables.

2.4. Random forest model

A random forest model was trained to predict stocks of SOC across the NPCTR in R (v.3.4; R Core Team 2018 (www.R-project.org)) using the R-package randomForest (4.6; Liaw and Wiener 2002). Random forests grow a large number of regression trees (Breiman *et al* 1984) from different random subsets of training data and predictor variables, thereby reducing variance relative to single trees, and greatly reducing the risk of over-fitting model predictions and non-optimal solutions—though at the cost of interpretability (Breiman 2001). The transboundary database SOC stocks and associated covariates were first split into training (80%) and testing (20%) data and the model was parameterized to grow 5000 trees. For each tree, a subsample equivalent to $\frac{1}{4}$ of the total sample size was utilized (with replacement). Node size was set at 4 to minimize the out-of-bag error based on preliminary testing. Model performance was measured from goodness-of-fit, distributions of residuals, and predictions of test SOC stocks. Confidence intervals were computed using an infinitesimal jack-knife procedure (Wager *et al* 2013). Predictions were made across the NPCTR study extent using R-package *raster* (v2.6; Hijmans 2017) which produced a SOC map at 90.5 m resolution. All lakes >10 ha were clipped from the final map (HydroLakes, Messager *et al* 2016) and glacier area was clipped using the Randolph Glacier Inventory 5.0 (GLIMS, Raup *et al* 2007) database. Final SOC stocks were adjusted for topography by scaling the SOC map with actual land surface area calculated from cell slope values. The random forest model was re-run for the three gap-filling sensitivity analyses (see SI—the final SOC map is available at: <https://datadryad.org/resource/doi:10.5061/dryad.5jf6j1r> (Dryad)).

2.5. Comparison to regional and global maps

Stocks of SOC were compared with two previous Alaskan studies, two regional/national models, and two global models (table 1). Published summary statistics for NPCTR regions were either referred to directly (Johnson *et al* 2011) or estimated from published data (Michaelson *et al* 2013). The Canadian SOC map produced by Tarnocai and Lacelle (1996) was regionalized, rasterized, and resampled to extract pixels that overlapped with the study boundary and methods to calculate mean and total SOC stocks were replicated (available at: <http://sis.agr.gc.ca/cansis/interpretations/carbon/index.html>). Two global SOC maps, SoilGrids250m (Hengl *et al* 2017) and the Global Soil Organic Carbon map (GSOC, FAO and ITPS 2018), were downloaded as rasters and resampled from 250 m and 1 km resolutions, respectively. SoilGrids 250 m was built from a database of ca. 150 000 soil profiles and a stack of 158 covariates to produce a continuous global surface of SOC stock to 1 m, whereas the FAO GSOC map is a composite of national SOC stock assessments and covers a depth of 0–30 cm. Genet *et al* (2018) estimated SOC across the N. Pacific Landscape Conservation Cooperative using pedons from relevant forest cover types in SEAK. Differences in SOC stocks are explored quantitatively in the context of different extents, gap-filling procedures, and data sources. Finally, the predictive accuracy and bias of the random forest model, is compared to two global SOC products (SoilGrids250m and the FAO GSOC map).

2.6. Spatial controls of SOC

To explore controls on SOC stocks across the NPCTR, classification and regression trees (CART) was applied to the transboundary SOC database using R-package *rpart* (v4.1, Therneau and Atkinson 2018). Unlike weak learner regression trees grown in random forests, CART analyses fit to entire datasets provide readily interpretable outputs. CART is also well suited to interpretation of complex data with many interacting variables, non-normally distributed data, and can identify key covariate interactions and thresholds.

3. Results

3.1. Summary of PCTR observations

Pedon SOC stocks and depths were log-normally distributed (supplementary figures 2(a)–(d)). Median soil depth across all the samples was 66 cm and median calculated SOC density was 168.4 Mg ha⁻¹. Other database summary statistics are provided in supplementary table 7. Soil classes in the pedon database were mostly Spodosols (426), Inceptisols (214), and Entisols (84), with fewer Histosols (70) and Folists (9).

Sample locations were generally well distributed across the study extent with some clustering around S Vancouver Is., N BC, and central SEAK (figure 1; supplementary figures 2(e) and (f)). The distributions of the environmental covariate data extracted at pedons

Table 1. Comparison of methods and results of NPCTR SOC stocks estimated in this study and other regional and global SOC studies.

Study	Scale	Region	Method	Mean SOC ^a (Mg ha ⁻¹)	Total SOC ^b (Pg C)
Present Study	Regional	NPCTR Watersheds	Random Forest	228 ± 111	4.5
<i>Present Study—Sens. Test</i>			+ <i>High Bulk Density</i>	329 ± 160	6.5
<i>Present Study—Sens. Test</i>			+ <i>High Mineral %C</i>	249 ± 125	4.9
<i>Present Study—Sens. Test</i>			+ <i>No Coarse Fra.</i>	224 ± 118	4.5
Johnson <i>et al</i> (2011)	Regional	Coastal Rainforests (Upland)	Database Summary Stats.	240 ± 132	—
Johnson <i>et al</i> (2011)	Regional	Coastal Rainforests (Lowland)	Database Summary Stats.	258 ± 174	—
Michaelson <i>et al</i> (2013)	Regional	SE Alaska	Database Summary Stats.	587 ± 379	—
Tarnocai and Lacelle (1996)	National	Regionalized to NPCTR (BC only)	Soil Map Unit Assignment	294 ± 180	3.4 ^c
Leighty <i>et al</i> (2006)	State	Tongass Nat. Forest(AK)	Econometric Flow Chart	—	1.9 ^c
Genet <i>et al</i> (2018)	State	North Pacific Coast LLC (AK)	Land Cover Class	—	4.8 ^c
SoilGRIDS250m (Hengl <i>et al</i> 2017)	Global	Regionalized to NPCTR	Random Forest	486 ± 149	18.0
GSOC (FAO and ITPS 2018)	Global	Regionalized to NPCTR	US: Soil Map Unit BC: Ensemble	136 ± 60	2.5 ^d

^a Map of database mean ±SD; a dash denotes no means reported.

^b SOC stock for overlap extent with present study (unless otherwise noted); a dash denotes no regional prediction.

^c Partially overlap extent with this study. Genet *et al* (2018) extent excludes BC but includes maritime upland and alder forest cover across southeast and south central Alaska.

^d The FAO Global SOC map extends only to 30 cm depth.

were generally very similar to the distributions of covariates across the region (supplementary figures 2(e)–(n)). Samples were slightly biased to lower and less steep areas, and the presence of large icefields and high alpine (not sampled) explained discrepancies in percent forest cover and land cover classes.

3.2. Random forest SOC model performance

Model performance was strongest for larger scale patterns in SOC. Though predictive performance on test data by the random forest model was low ($R^2 = 0.32$), the model covariates were representative of the region (supplementary figure 2), the mean of the residuals was zero, and largest errors were underestimations in areas otherwise correctly predicted to have higher than typical SOC (supplementary figure 3). We therefore have high confidence in model predictions for the regional scale patterns in SOC, with less confidence for variation at finer spatial scales. The predictions of the random forest in this study were more accurate (figure 2) compared to those extracted from two global products SoilGrids250 and the FAO GSOC map at the same locations (figure 2).

3.3. Estimates of SOC stocks

Total SOC within the NPCTR of SEAK and BC was estimated at 4.5 Pg C (table 1) with highest stocks ($> 500 \text{ Mg ha}^{-1}$) found in the central islands of SE Alaska and westerly locations, and lower stocks ($< 200 \text{ Mg ha}^{-1}$) predicted for more southerly and easterly locations. Sensitivity analyses indicated that SOC stock estimates were most sensitive to bulk density gap-filling assumptions as estimates increased by approximately 50% after increasing organic horizon bulk density ca. 3-fold to 0.33 g cm^{-3} (supplementary table 5). From the fractional increase in SOC caused by the tripling of organic horizon bulk density, we computed that 22% of the predicted NPCTR SOC stocks must be stored in organic soil horizons.

3.4. Environmental covariates of SOC stock

CART analysis (figure 3) showed that the lowest SOC stocks ranging from 128.5 to 194.8 Mg ha^{-1} were associated with the driest ($< 2147 \text{ mm MAP}$), southeasterly locations. Intermediate stocks ($252.7\text{--}442.9 \text{ Mg ha}^{-1}$) were assigned to wetter climates at higher topographic positions (upslope). Very high SOC stocks ($336.0\text{--}523.3 \text{ Mg ha}^{-1}$) were also associated with wet climate areas ($2147\text{--}2833 \text{ mm}$) on foot-slope (downslope) landscape positions. Finally, exceptionally high SOC stocks of $446.2\text{--}708.6 \text{ Mg ha}^{-1}$ were assigned to the wettest climates ($> 2833 \text{ mm}$) at relatively low elevations ($< 189 \text{ m}$).

4. Discussion

4.1. SOC stocks in the global context

The estimated 4.5 Pg C stored within perhumid and the northern seasonal NPCTR watersheds indicates

the region contains approximately 2% of North American SOC within less than 1% of its surface area (Köchy *et al* 2015). Using a simple upscaling from study region mean stocks ($228 \pm 111 \text{ Mg ha}^{-1}$) to global CTR extent (ca. $9.7 \times 10^5 \text{ km}^2$; Alaback 1991) we can estimate that $22 \pm 11 \text{ Pg C}$ may be stored globally in CTR ecosystems. These estimates are likely conservative due to our 1 m depth range, our assumption that the coarse fraction is entirely mineral (Zabowski *et al* 2011), the abundance of deep (3–5 m) peat-forming fens that can form in wet landscape depressions (supplementary figures 5 and 6) that are smaller than our spatial resolution (Heusser 1952, D'Amore and Lynn 2002), as well as the likely occurrence of cryptic wetlands hidden within forests (Creed *et al* 2003).

In a review of global SOC, Jackson *et al* (2017) calculated the first biome-specific SOC stocks, estimating that 64 Pg C is stored in ca. 6 M km^2 of non-permafrost soils in temperate conifer forests. Our results disaggregate this result further, suggesting CTRs within the temperate conifer forest biome contain one-third of the total SOC, while representing less than one-sixth of the biome's area. Jackson *et al* (2017) also estimated that 22% (14 Pg) of the SOC was stored in organic peatlands, which matched exactly our estimate of the proportion of SOC in organic soil (peatlands and surface organic accumulations). The agreement, while remarkable, is not truly scalable, but it does likely reflect a common suite of C input and stabilization mechanisms in cool, wet temperate conifer forest ecosystems that may lead to consistent partitioning of stocks between mineral and organic soils.

As has been demonstrated for aboveground biomass (Keith *et al* 2009), SOC densities in the CTR appear to rank among the highest globally. The mean SOC stock estimate from this study ($228 \pm 111 \text{ Mg ha}^{-1}$) positions the NPCTR below estimates for permafrost soils ($178\text{--}691 \text{ Mg ha}^{-1}$; 5th–95th percentile), but substantially higher SOC densities than grasslands ($56\text{--}289 \text{ Mg ha}^{-1}$), evergreen broadleaf forests ($83\text{--}223 \text{ Mg ha}^{-1}$), and croplands ($60\text{--}200 \text{ Mg ha}^{-1}$), and within a similar range as permanent wetlands ($114\text{--}474 \text{ Mg ha}^{-1}$, Sanderman *et al* 2018b). Our results also suggest SOC densities to 1 m in temperate rainforests are higher than in tropical rainforests ($85\text{--}271 \text{ Mg ha}^{-1}$) perhaps in part due to litter accumulations which are typically absent in tropical rainforest floors due to very favorable conditions for decomposition (Parton *et al* 2007).

4.2. Model comparisons

Estimated SOC stocks agreed with some past estimates of SOC storage in Alaskan coastal rainforests (table 1). The two regional/national studies that approximate SEAK (Tongass National Forest, Leighty *et al* 2006) and BC (Tarnocai and Lacelle 1996), when summed, produced an estimate of 5.3 Pg C compared to our

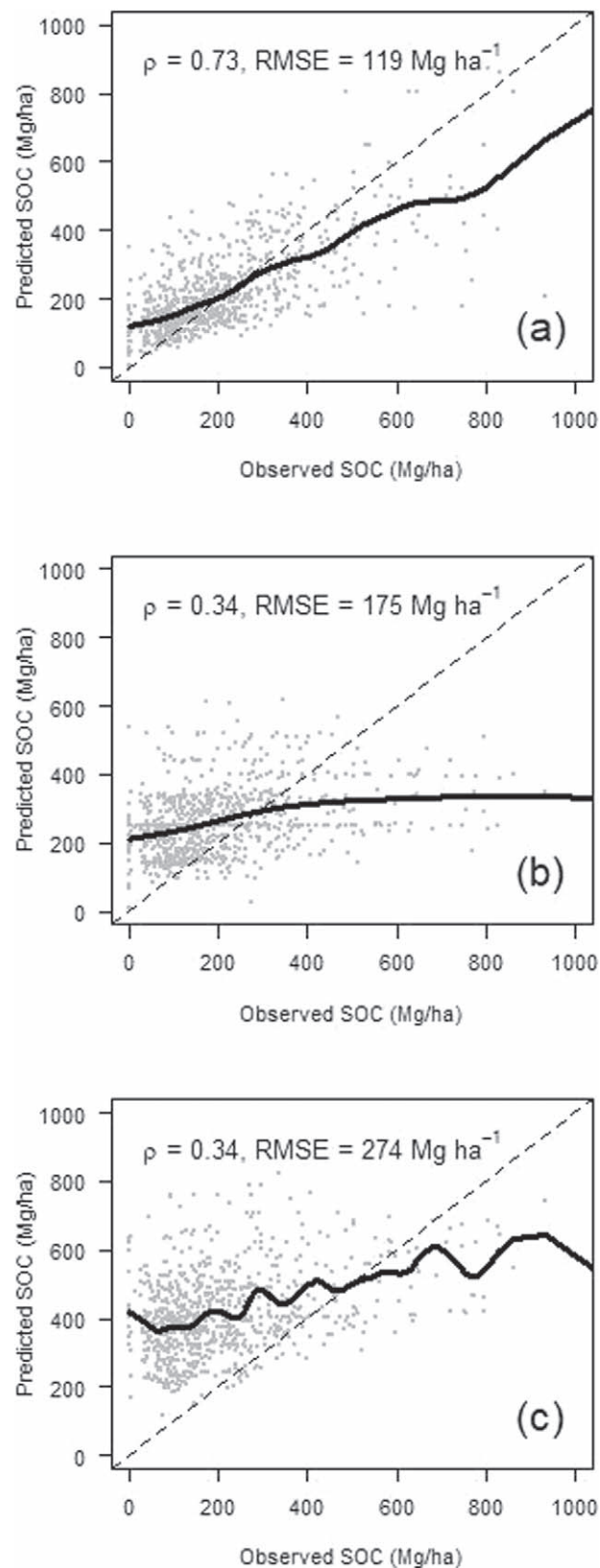
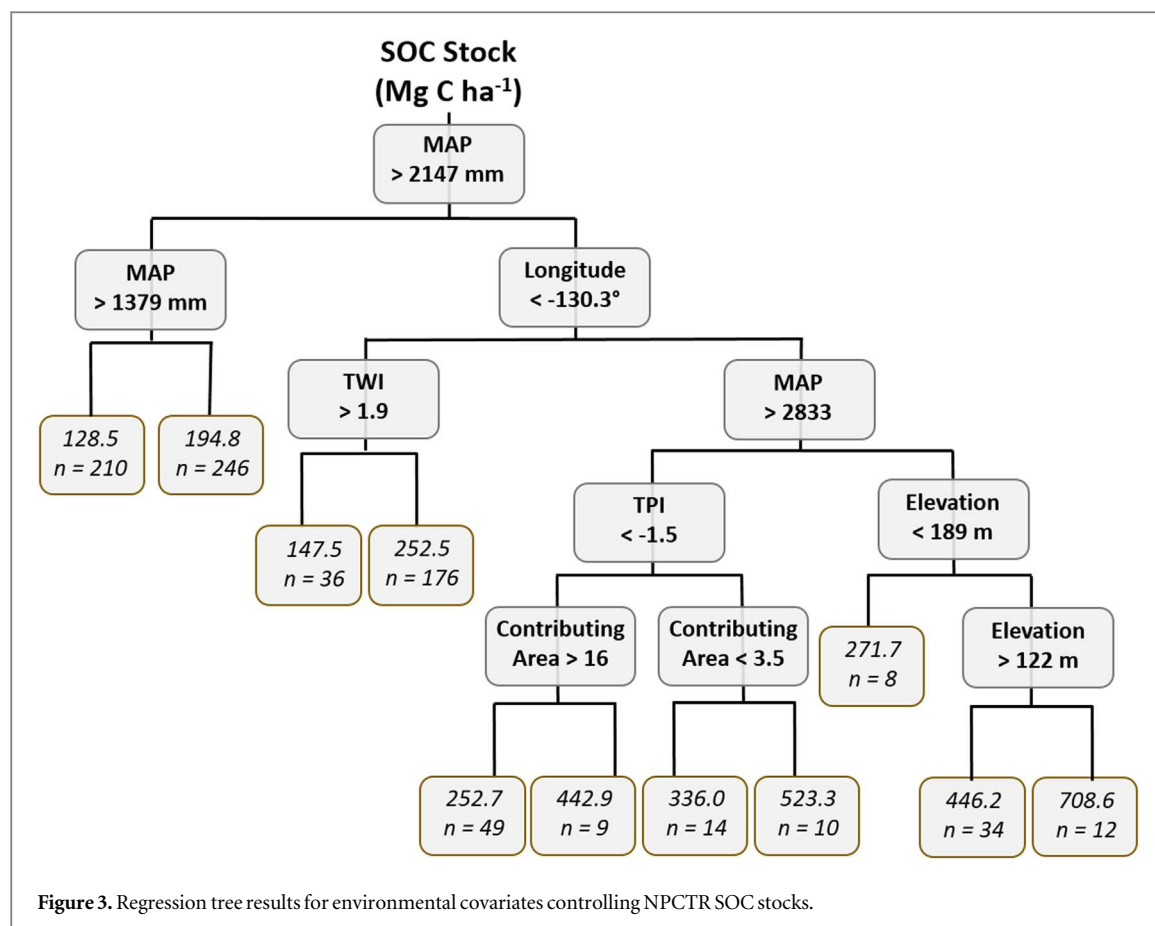


Figure 2. Predicted versus observed SOC stocks (Mg ha^{-1}) for individual database profile locations compared for (a) this study's spatial predictions, (b) the FAO GSOC map, and (c) SoilGrids250m, with smooth spline fits (solid line) and 1:1 line (dashed). Pearson's correlation coefficients (ρ) and root mean squared error (RMSE) between predicted and observed values are reported for each model. Note FAO predictions (for 0–30 cm) are doubled assuming approximately 50% of SOC stocks are stored from 30–100 cm depth (James *et al* 2014).

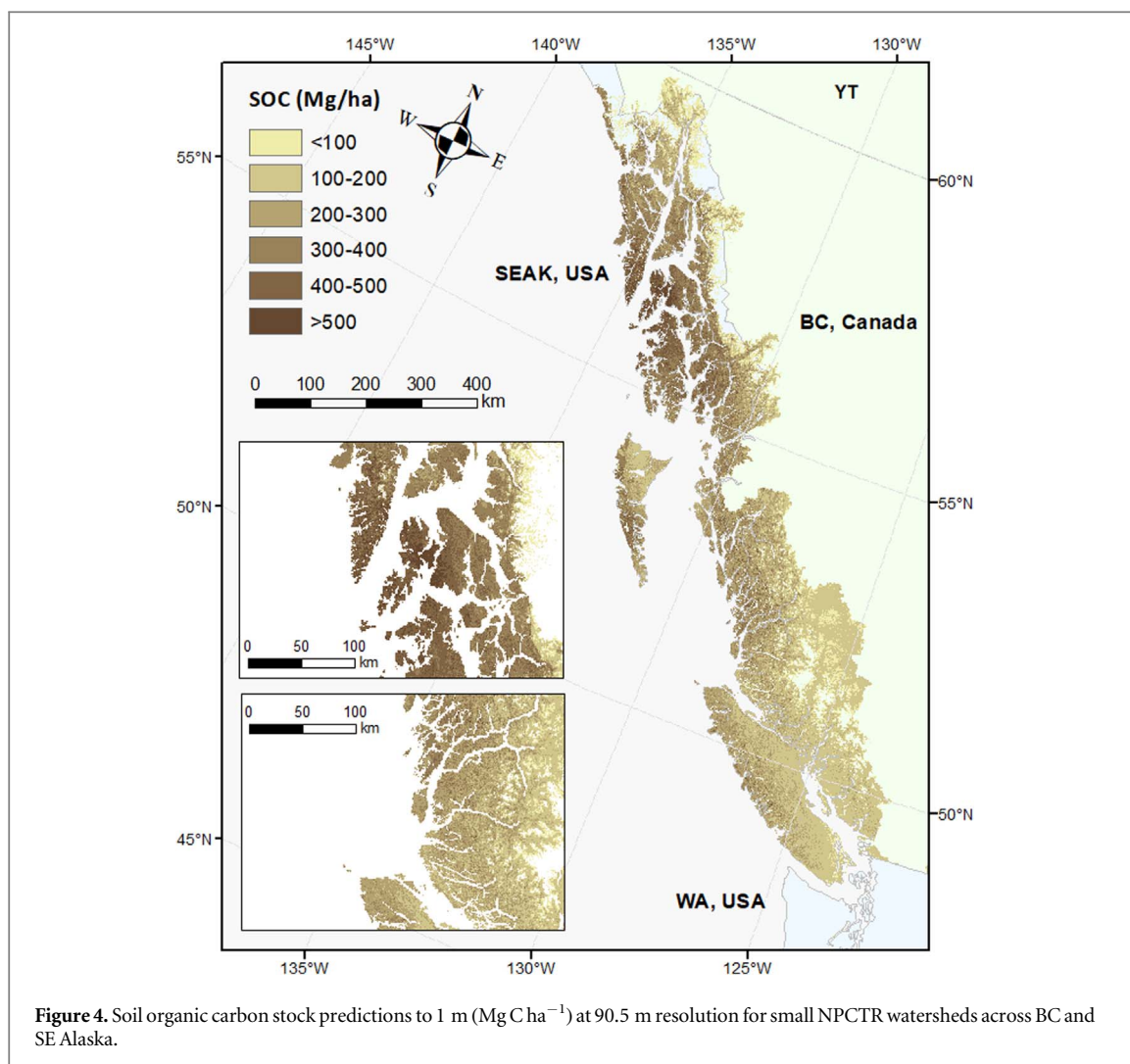


estimate of 4.5 Pg C. However, Tarnocai and Lacelle (1996) integrated SOC to the full observed depth of organic soils which was found to be approximately ~1.51 m, or ~50% greater than the reference depth in this study (1 m), which may explain the larger estimate. The GSOC map estimated lower SOC stocks (2.5 Pg C) because it only considers the top 30 cm of soil, but if it is assumed that ca. 50% of the SOC stock is stored from 30 to 100 cm (James *et al* 2014), then the estimates (~5 Pg C) align well with the present study.

For one study and two global SOC products we identified large discrepancies with our SOC predictions. The global model SoilGrids250m and the regional Alaska database produced by Michaelson *et al* (2013) were outliers in our comparison, predicting 4-fold higher total SOC for the region, and 2 or 3-fold higher mean SOC, respectively (table 1). Our model also more accurately predicted the spatial variation in SOC across the NPCTR relative to the FAO GSOC map and SoilGrids250m (figure 2). Both global products showed strong bias for the region, with overestimates where we predict lower stocks and weak correlation with the observed variability overall. Finally, unrealistic spatial discontinuities are present in the FAO GSOC map at the US-Canada border that did not exist in our transboundary assessment (figure 5). Global SOC maps created from a mosaic of national inventories clearly benefit where nations

conduct quality SOC assessments, evidenced by the reasonable summed stock estimates of GSOC for the NPCTR (table 1). However, we propose that biome-specific assessments are better than national inventories because spatial discontinuities that form within global mosaics will fall along ecologically significant, rather than arbitrary political, boundaries (Ramcharan *et al* 2017).

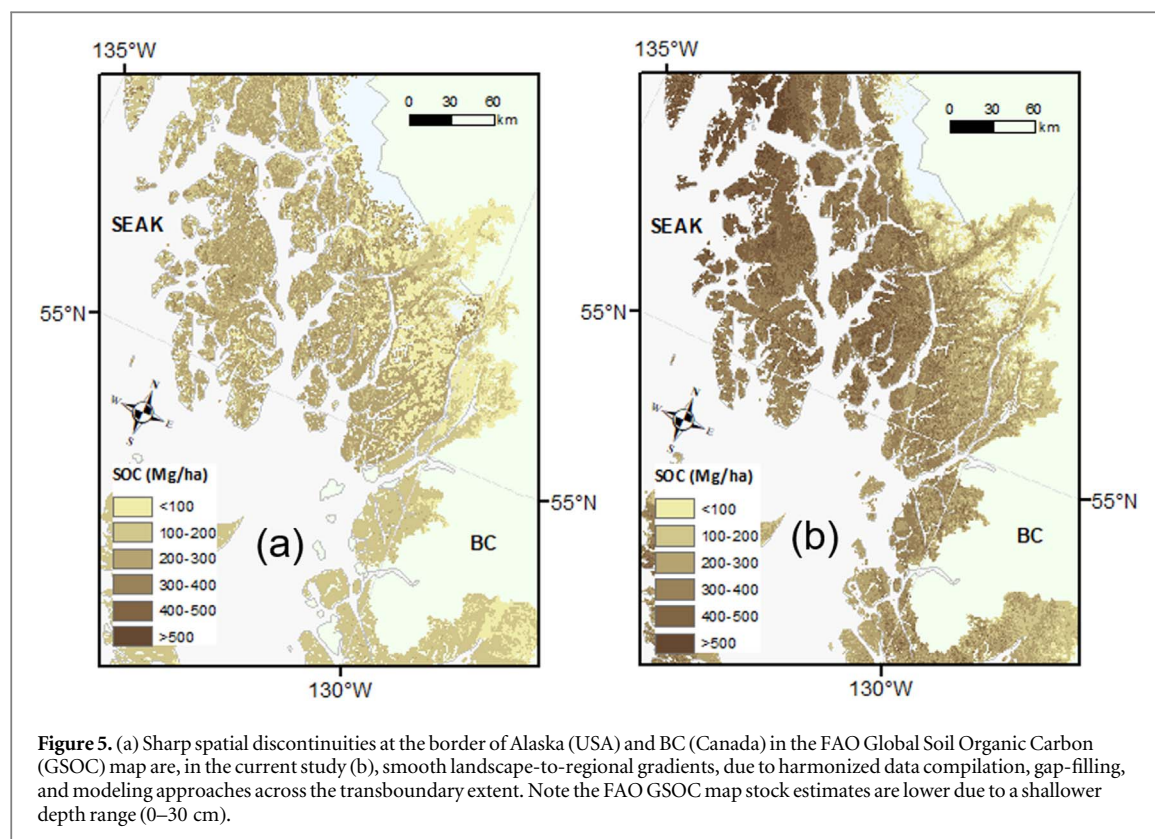
The bulk density gap-filling procedure applied by Michaelson *et al* (2013) was not replicated in this study due to the observation that the pedotransfer functions (Van Looy *et al* 2017) relating %C to bulk density overestimate organic layer (high %C) bulk density by up to 4-fold relative to published values (supplementary figure 4; Shaw *et al* 2005). Using these pedotransfer functions would bias the SOC estimates too high in the NPCTR where organic soils are common (D'Amore *et al* 2010) and forest floor organic horizons are often deep (Kranabetter and Banner 2000). Direct comparison of our database with that of Michaelson *et al* (2013) illustrates how gap-filling procedures can lead to very different SOC estimates. Similar issues may underlie discrepancies observed with SoilGrids250m (18 Pg C; table 1). Models built using the Harmonized World Soil Database and SoilGrids250m have been gap-filled using pedotransfer functions that may overestimate organic soil bulk density and lead to overestimated SOC stocks (Köchy *et al* 2015). A recent



global model comparison found much larger SOC stock estimates using the SoilGrids database than from other global databases (Tifafi *et al* 2018). Our study similarly suggests SoilGrids250m overestimates SOC stocks within the NPCTR, and possibly in other organic and/or high-latitude soils (figure 2(c)). We cannot however explain the differences with organic soil bulk density alone, based upon our sensitivity analysis where bulk density was tripled. We therefore propose that the juxtaposition of highly contrasting soils in the NPCTR (supplementary figures 5 and 6) may make the region particularly susceptible to SOC errors when aggregating and modeling pedon observations. In the NPCTR, C-rich litter layers and organic soils lie adjacent (vertically and laterally) to mineral soils (Michaelson *et al* 2013, Shaw *et al* 2018) and, without separate representation during gap-filling or modeling steps values may be artificially inflated. Populating the database and calculating SOC on the basis of pedological information, including distinguishing surface organic from subsurface mineral horizons, may have improved SOC variable estimation in this study.

4.3. Covariates of NPCTR SOC stocks

Digital soil mapping assumes properties, such as SOC, can be predicted spatially across landscapes from the distribution of geospatial covariates related to the classical factors of soil formation (Jenny 1994, Minasny 2013). We found that high precipitation is the primary control on SOC storage in the NPCTR; SOC stocks tracked regional gradients in MAP, and longitude, with the highest stocks in the north coast of BC and central SEAK (figures 3 and 4). Topographic attributes including elevation, wetness, and slope position, which modulate temperature and soil moisture conditions, also emerged as important controls. Land cover was not a strong predictor, however, both the region and pedon database, are dominated by conifer forest which does not distinguish between upland soils and forested wetland coverage. Though lithology has been shown to be important across Alaska generally as a predictor of SOC stocks (Mishra and Riley 2012), we did not find support for lithology as a broadly important covariate. However, lithology is an imperfect indicator of parent material for soil



formation across the region due to the extensive presence of glacial deposits.

4.4. Vulnerabilities of NPCTR SOC stocks

Stocks of SOC in the NPCTR may be sensitive to several climate-related changes in the coming century, but the overall direction of effects is uncertain. Wolken *et al* (2011) highlighted loss of winter snow and ice as the most important biophysical change in the CTRs of Alaska, driven by projected average temperature increases of $3.5^{\circ}\text{C} \pm 1.5^{\circ}\text{C}$ by 2100. Based upon the primacy of MAP and topographic wetness in our analyses, both higher predicted MAP and a reduction in the proportion as snow (Shanley *et al* 2015) may expand the spatial and temporal domain for high SOC accumulations in the NPCTR. However, this may be balanced by increases in lateral exports of terrestrial DOC, which is already a distinctively large component of NPCTR ecosystem C budgets (Oliver *et al* 2017). Similarly, effects of temperature may be bi-directional. Elevated temperatures lead to rapid decomposition of NPCTR soil organic matter under laboratory conditions (Fellman *et al* 2017) however it is unclear to what degree this effect will be limited by the saturated soil conditions *in situ*, which constrain decomposition rates (Freeman *et al* 2001), or offset by concurrent increases in SOC inputs via enhanced primary productivity and litterfall (Buma *et al* 2016, Genet *et al* 2018).

4.5. SOC modeling considerations

Our study shows that digital soil mapping can be valuable across the NPCTR where soil survey and conventional soil mapping is challenging (Carpenter *et al* 2014), however a baseline of high quality pedon data is still essential for accurate predictions. Vitharana *et al* (2017) found that existing data for SE Alaska well represented environmental variability and our covariate data distributions (supplementary figure 2) agree with this conclusion, however, much of the central and northern BC coastline is less well sampled (figure 1) and those data we did obtain required extensive gap-filling. Our model also under-predicted the largest SOC stocks which, as random forests subset data to grow each tree, may be due to relatively few observations of very high SOC.

Model improvements may also be possible if input covariate datasets and the final map are obtained at finer spatial resolution. For example, the NPCTR displays complex topography that may not be fully resolved at 90 m. Mishra and Riley (2015) found that soil wetness (derived from landform) and aspect were lost as significant predictors of Alaskan C stocks when moving from a 50 to a 100 m resolution. Similarly, Siewert (2017) compared a wide range of resolutions (2–1000 m) for random forest predictions of a sub-Arctic peatland SOC stocks in Sweden and found resolutions >30 m led to underestimates. Building models using more accurately georeferenced pedon data and more finely resolved (<50 m) covariate surfaces may improve spatial predictions of SOC.

5. Conclusions

Regional SOC stock assessments can validate and improve global maps by considering drivers, and compiling datasets, in greater detail. We compiled a SOC database for the NPCTR, using pedology data to guide gap-filling and predictive modeling. Regression tree models predicted high SOC stocks in wet coastal watersheds, indicating that the CTR represents a moisture-dependent hotspot for SOC at mid-latitudes.

Contributions

BB, DB, and AB conceived of the project. PS, CB, SS, and DD provided data for, and supervised GM during the compilation, and gap-filling of, the transboundary NPCTR SOC database. BB supervised GM on random forest and CART analyses. IG, SA, and PS created NPCTR digital surface products and provided unpublished data from digital soil mapping efforts by the Hakai Institute in 2014 and 2016. CB and SS provided BEC and BCSIS datasets and CB supervised GM in gap-filling of BEC pedon data. GM and BB authored the first draft of the manuscript and CB, DD, PS, IG, AB, and DB contributed to later drafts.

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References

- Alaback P B 1991 Comparative ecology of temperate rainforests of the Americas along analogous climatic gradients *Rev. Chil. Hist. Nat.* **64** 399–412
- Breiman L 2001 Random forests *Mach. Learn.* **45** 5–32
- Breiman L, Friedman J H, Olshen R A and Stone C G 1984 *Classification and Regression Trees* (Belmont, CA: Wadsworth International Group)
- Buma B and Barrett T M 2015 Spatial and topographic trends in forest expansion and biomass change, from regional to local scales *Glob. Change Biol.* **21** 3445–54
- Buma B, Krapek J and Edwards R T 2016 Watershed-scale forest biomass distribution in a perhumid temperate rainforest as driven by topographic, soil, and disturbance variables *Can. J. For. Res.* **46** 844–54
- Carpenter D N, Bockheim J G and Reich P F 2014 Soils of temperate rainforests of the North American pacific coast *Geoderma* **230–231** 250–64
- Chandler R F 1943 The time required for Podzol profile formation as evidenced by the Mendenhall glacial deposits near Juneau, Alaska *Soil Sci. Soc. Am. J.* **7** 454–9
- Creed I F, Sanford S E, Beall F D, Molot L A and Dillon P J 2003 Cryptic wetlands: integrating hidden wetlands in regression models of the export of dissolved organic carbon from forested landscapes *Hydrol. Process.* **17** 3629–48
- D'Amore D V, Fellman J B, Edwards R T and Hood E 2010 Controls on dissolved organic matter concentrations in soils and streams from a forested wetland and sloping bog in southeast Alaska *Ecology* **91** 249–61
- D'Amore D V and Lynn W C 2002 Classification of forested Histosols in southeast Alaska *Soil Sci. Soc. Am. J.* **66** 554
- D'Amore D V, Ping C-L and Herendeen P A 2015 Hydromorphic soil development in the coastal temperate rainforest of Alaska *Soil Sci. Soc. Am. J.* **79** 698
- Davidson E A and Janssens I A 2006 Temperature sensitivity of soil carbon decomposition and feedbacks to climate change *Nature* **440** 165–73
- DellaSala D A 2011 Temperate and boreal rainforests of the Pacific coast of North America *Temperate and Boreal Rainforests of the World: Ecology and Conservation* ed D A DellaSala (Washington, DC: Island Press) pp 42–82
- Eamer J B R, Shugar D H, Walker I J, Lian O B, Neudorf C M and Telka A M 2017 A glacial readvance during retreat of the Cordilleran Ice Sheet, British Columbia central coast *Quat. Res.* **87** 468–81
- FAO and ITPS 2018 *Global Soil Organic Carbon Map (GSOCCmap) Technical Report 162* FAO and ITPS (Rome)
- Farr W A and Hard J S 1987 *Multivariate analysis of climate along the southern coast of Alaska—some forestry implications* 38 US Department of Agriculture, Forest Service, Pacific Northwest Research Station p 372
- Fellman J B, D'Amore D V, Hood E and Cunningham P 2017 Vulnerability of wetland soil carbon stocks to climate warming in the perhumid coastal temperate rainforest *Biogeochemistry* **133** 165–79
- Fox C and Tarnocai C 2011 Organic soils of Canada: II. Upland organic soils *Can. J. Soil Sci.* **91** 823–42
- Freeman C, Ostle N and Kang H 2001 An enzymic 'latch' on a global carbon store *Nature* **409** 149
- Genet H *et al* 2018 The role of driving factors in historical and projected carbon dynamics of upland ecosystems in Alaska *Ecol. Appl.* **28** 5–27
- Gonzalez Arriola S, Giesbrecht I, Biles I J W and D'Amore D V 2018 Watersheds of the northern Pacific coastal temperate rainforest margin: internationally harmonized watershed polygons at the finest scale available (Hakai Inst. Data Package) (<https://doi.org/10.21966/1.715755>)
- Hansen H 1955 Postglacial forests in south-central and central British Columbia *Am. J. Sci.* **253** 640–58
- Hengl T *et al* 2017 SoilGrids250m: global gridded soil information based on machine learning *PLoS ONE* **12** e0169748

- Heusser C J 1952 Pollen Profiles from Southeastern Alaska *Ecol. Monogr.* **22** 331–52
- Heusser C J 1954 Additional pollen profiles from Southeastern Alaska *Am. J. Sci.* **252** 106–19
- Hijmans R J 2017 raster: Geographic Data Analysis and Modeling. R package version 2.6-7
- Hugelius G, Strauss J, Zubrzycki S, Harden J W, Schuur E A G, Ping C and Schirmermeister L 2014 Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps *Biogeosciences* **11** 6573–93
- Hugelius G, Tarnocai C, Broll G, Canadell J G, Kuhry P and Swanson D K 2013 The northern circumpolar soil carbon database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions *Earth Syst. Sci. Data* **5** 3–13
- Jackson R B, Lajtha K, Crow S E, Hugelius G, Kramer M G and Piñeiro G 2017 The Ecology of Soil Carbon: Pools, Vulnerabilities, and Biotic and Abiotic Controls *Annu. Rev. Ecol. Evol. Syst.* **48** 112414–054234
- James J, Devine W, Harrison R and Terry T 2014 Deep soil carbon: quantification and modeling in subsurface layers *Soil Sci. Soc. Am. J.* **78** S1
- Jenny H 1994 *Factors of Soil Formation. A System of Quantitative Pedology* vol 68 (New York: Dover)
- Johnson K D *et al* 2011 Soil carbon distribution in Alaska in relation to soil-forming factors *Geoderma* **167–168** 71–84
- Keith H, Mackey B G and Lindenmayer D B 2009 Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests *Proc. Natl Acad. Sci.* **106** 11635–40
- Köchy M, Hiederer R and Freibauer A 2015 Global distribution of soil organic carbon: I. Masses and frequency distributions of SOC stocks for the tropics, permafrost regions, wetlands, and the world *Soil* **1** 351–65
- Kranabetter J M and Banner A 2000 Selected biological and chemical properties of forest floors across bedrock types on the north coast of British Columbia *Can. J. For. Res.* **30** 971–81
- Leighty W W, Hamburg S P and Caouette J 2006 Effects of management on carbon sequestration in forest biomass in southeast Alaska *Ecosystems* **9** 1051–65
- Liaw A and Wiener M 2002 Classification and Regression by random forest *R News* **2** 18–22
- Lin H, Bouma J, Pachepsky Y, Western A, Thompson J, Van Genuchten R, Vogel H J and Lilly A 2006 Hydopedology: synergistic integration of pedology and hydrology *Water Resour. Res.* **42** 1–13
- Messenger M L, Lehner B, Grill G, Nedeva I and Schmitt O 2016 Estimating the volume and age of water stored in global lakes using a geo-statistical approach *Nat. Commun.* **7** 1–11
- Michaelson G J, Ping C and Clark M 2013 Soil pedon carbon and nitrogen data for Alaska: an analysis and update *Open J. Soil Sci.* **3** 132–42
- Minasny B, McBratney A B, Malone B P and Wheeler I 2013 Digital mapping of soil carbon *Advances in Agronomy* vol 118 (Amsterdam: Elsevier) pp 1–47
- Mishra U and Riley W J 2012 Alaskan soil carbon stocks: spatial variability and dependence on environmental factors *Biogeosciences* **9** 3637–45
- Mishra U and Riley W J 2015 Scaling impacts on environmental controls and spatial heterogeneity of soil organic carbon stocks *Biogeosciences* **12** 3993–4004
- Neiland B J 1971 The forest-bog complex of southeast Alaska *Veg. Acta Geobot.* **22** 1–64
- Nowacki G J, Spencer P, Fleming M, Brock T and Jorgenson T 2003 Unified Ecoregions of Alaska: 2001 (<https://doi.org/10.3133/ofr2002297>)
- Oliver A A, Tank S E, Giesbrecht I, Korver M C, Floyd W C, Sanborn P, Bulmer C and Lertzman K P 2017 A global hotspot for dissolved organic carbon in hypermaritime watersheds of coastal British Columbia *Biogeosciences* **14** 3743–62
- Parton W *et al* 2007 Global-scale similarities in nitrogen release patterns during long-term decomposition *Science* **5064** 361–4
- R Core Team 2018 R: A Language and Environment for Statistical Computing (R Foundation for Statistical Computing, Vienna)
- Ramcharan A, Hengl T, Nauman T, Brungard C, Waltman S, Wills S and Thompson J 2017 Soil property and class maps of the conterminous US at 100 meter spatial resolution based on a compilation of national soil point observations and machine learning *Soil Sci. Soc. Am. J.* **82** ([arXiv.org/abs/1705.08323](https://arxiv.org/abs/1705.08323))
- Raup B, Racoviteanu A, Khalsa S J S, Helm C, Armstrong R and Arnaud Y 2007 The GLIMS geospatial glacier database: a new tool for studying glacier change *Glob. Planet. Change* **56** 101–10
- Sanderman J *et al* 2018a Correction for Sanderman *et al*, Soil carbon debt of 12 000 years of human land use *Proc. Natl Acad. Sci.* **115** E1700
- Sanderman J *et al* 2018b A global map of mangrove forest soil carbon at 30 m spatial resolution *Environ. Res. Lett.* **13** 055002
- Sanderman J, Hengl T and Fiske G J 2017 Soil carbon debt of 12000 years of human land use *Proc. Natl Acad. Sci.* **114** 9575–80
- Shanley C S, Pyare S, Goldstein M I, Brinkman T J, Edwards R T and Hood E 2015 Climate change implications in the northern coastal temperate rainforest of North America *Clim. Change* **130** 155–70
- Shaw C, Bhatti J and Sabourin K 2005 *An ecosystem carbon database for Canadian forests (Information Report NOR-X-403)* Natural Resources Canada, Canadian Forest Service, Northern Forestry Center, (Edmonton, Alta)
- Shaw C, Hilger A, Filiatrault M and Kurz W 2018 A Canadian upland forest soil profile and carbon stocks database *Ecology* **99** 2159
- Siewert M B 2017 High-resolution digital mapping of soil organic carbon in permafrost terrain using machine-learning: a case study in a sub-Arctic peatland environment *Biogeosciences* **15** 1–36
- Tarnocai C and Lacelle B 1996 Soil organic carbon digital database of Canada. Eastern Cereal Oilseed Research Centre, Research Branch, Agriculture and Agri-Food Canada, Ottawa (<http://sis.agr.gc.ca/cansis/interpretations/carbon/index.html>)
- Therneau T and Atkinson B 2018 Rpart: recursive partitioning and regression trees *R-Package Version 4*. 1–13 (<https://CRAN.R-project.org/package=rpart>)
- Tifafi M, Guenet B and Hatté C 2018 Large differences in global and regional total soil carbon stock estimates based on SoilGrids, HWSD and NCSCD: intercomparison and evaluation based on field data from USA, England, Wales and France *Glob. Biogeochem. Cycles Under Revi* 1–15
- Todd-Brown K E O, Randerson J T, Post W M, Hoffman F M, Tarnocai C, Schuur E A G and Allison S D 2013 Causes of variation in soil carbon simulations from CMIP5 Earth system models and comparison with observations *Biogeosciences* **10** 1717–36
- Ugolini F C and Mann D H 1979 Biopedological origin of peatlands in South East Alaska *Nature* **281** 366–8
- Van Hees W W S 2003 Forest resources of southeast Alaska, 2000: results of a single-phase systematic sample *Res. Pap PNW-RP-557*
- Van Looy K *et al* 2017 Pedotransfer functions in earth system science: challenges and perspectives *Rev. Geophys.* **55** 1199–256
- Vitharana U W A, Mishra U, Jastrow J D, Matamala R and Fan Z 2017 Observational needs for estimating Alaskan soil carbon stocks under current and future climate *J. Geophys. Res. Biogeosci.* **122** 415–29
- Wager S, Hastie T and Efron B 2013 Confidence intervals for random forests: the jackknife and the infinitesimal jackknife *J. Mach. Learn. Res.* **15** 1625–51
- Wolken J M *et al* 2011 Evidence and implications of recent and projected climate change in Alaska's forest ecosystems *Ecosphere* **2** 1–35
- Zabowski D, Whitney N, Gurung J and Hatten J 2011 Total soil carbon in the coarse fraction and at depth *For. Sci.* **57** 11–8

Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms

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Abstract

Multi-criteria decision analysis (MCDA) is an umbrella approach that has been applied to a wide range of natural resource management situations. This paper has two purposes. First, it aims to provide a critical review of MCDA methods applied to forest and other natural resource management. The review seeks to layout the nature of the models, their inherent strengths and limitations. Models are categorized based on different classification schemes and are reviewed by describing their general characteristics, approaches, and fundamental properties. The review goes beyond traditional MCDA techniques; it describes new modelling approaches to forest management. The second purpose is to describe new MCDA paradigms aimed at addressing the inherent complexity of managing forest ecosystems, particularly with respect to multiple criteria, multi-stakeholders, and lack of information. Comments about, and critical analysis of, the limitations of traditional models are made to point out the need for, and propose a call to, a new way of thinking about MCDA as they are applied to forest and natural resource management planning. These new perspectives do not undermine the value of traditional methods; rather they point to a shift in emphasis—from methods for problem solving to methods for problem structuring.

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1. Introduction

Belton and Stewart (2002) define multi-criteria decision analysis (MCDA) as, “an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter”. The general definition stated above outlines three dimensions of MCDA, namely: (1) the formal approach, (2) the presence of multiple criteria, and (3) that decisions are made either by individuals or groups of individuals. Invariably these dimensions are the main reasons why MCDA has been one of the most widely applied models in forest management, because they manifest some of the major forest management issues, namely: (1) the need for a structured and rational management approach that can integrate many of the key forest management elements, (2) the multi-functional or multiple uses of the forests, and (3) the

presence of multiple stakeholders and interest groups each with their own views, goals, and demands on how the forest should be managed.

Fundamentally, MCDA has inherent properties that make it appealing and practically useful. Belton and Stewart (2002) portrayed some of these properties as: (1) “it seeks to take explicit account of multiple, conflicting criteria”, (2) it helps to structure the management problem, (3) it provides a model that can serve as a focus for discussion, and (4) it offers a process that leads to rational, justifiable, and explainable decisions. Moreover, MCDA also has some desirable features that make it an appropriate tool for analysing complex problems such as those typically found in natural resource management. First, it can deal with mixed sets of data, quantitative and qualitative, including expert opinions. Data pertaining to, and knowledge about, forest ecosystems are seldom complete, known with certainty or fully understood. Hence, the capability to accommodate these gaps in information and knowledge through qualitative data, expert opinions, or experiential knowledge is a distinct advantage. Second, it is conveniently structured to enable a collaborative planning and decision-making environment. This participatory

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environment accommodates the involvement and participation of multiple experts and stakeholders (Mendoza and Prabhu, 2003).

The first objective of the paper is to provide a critical review of MCDA methods applied to forest and other natural resource management. The review, while not intended to be comprehensive, seeks to layout the nature of the models, their inherent strengths, capabilities, and limitations. Models are reviewed at the general classification level describing their general characteristics, approaches, and fundamental properties.

Only MCDA methods that consider the existence of a hierarchy of criteria (multiple objectives) and alternatives are considered. Therefore, other methods that deal with multi-objective planning, particularly those that use single objective optimisation with constraints as other goals, or use penalty functions, are not included. Comprehensive reviews of these methods can be found in Pukkala (2002) and Steiguer et al. (2003).

Many of the methods reviewed fall under what may generally be described as ‘hard’, or those consistent with the traditional and rational scientific management approach. The review, however, goes beyond traditional MCDA techniques; it describes new advances to forest management beyond the ‘hard’ management science view. This paper attempts to describe new MCDA paradigms in terms of addressing the inherent complexity of managing forest ecosystems, particularly with respect to their multiple dimensions (or components), the presence of multi-stakeholders, and the inevitable lack of information.

2. Classification of MCDM methods

MCDA approaches have been classified in a number of ways. One of the first categorizations makes a distinction between multi-objective decision making (MODM) and multi-attribute decision making (MADM). The main distinction between the two groups of methods is based on the number of alternatives under evaluation. MADM methods are designed for selecting discrete alternatives while MODM are more adequate to deal with multi-objective planning problems, when a theoretically infinite number of continuous alternatives are defined by a set of constraints on a vector of decision variables (Korhonen et al., 1992; Hayashi, 2000; Belton and Stewart, 2002). A more thorough distinction between these two groups of methods was made by Malczewski (1999) based on the differences pointed by Hwang and Yoon (1981) and Zeleny (1982). These differences are systematically summarized in Table 1.

The general classification of MCDA methods adopted in this paper is the one suggested by Belton and Stewart (2002) because it reflects more directly the range of their application. They classify MCDA methods into three broad categories:

- (1) *Value measurement models*: “numerical scores are constructed in order to represent the degree to which one decision option may be preferred to another. Such scores are developed initially for each individual criterion, and are

Table 1

Comparison of MODM and MADM approaches (Malczewski, 1999)

Criteria for comparison	MODM	MADM
Criteria defined by	Objectives	Attributes
Objectives defined	Explicitly	Implicitly
Attributes defined	Implicitly	Explicitly
Constraints defined	Explicitly	Implicitly
Alternatives defined	Implicitly	Explicitly
Number of alternatives	Infinite (large)	Finite (small)
Decision maker's control	Significant	Limited
Decision modelling paradigm	Process-oriented	Outcome-oriented
Relevant to	Design/search	Evaluation/choice

then synthesized in order to effect aggregation into higher level preference models”;

- (2) *Goal, aspiration or reference level models*: “desirable or satisfactory levels of achievement are established for each criterion. The process then seeks to discover options which are closest to achieving these desirable goals or aspirations”;
- (3) *Outranking models*: “alternative courses of action are compared pairwise, initially in terms of each criterion in order to identify the extent to which a preference for one over the other can be asserted. In aggregating such preference information across all relevant criteria, the model seeks to establish the strength of evidence favouring selection of one alternative over another”.

A more detailed description of the three groups can be found in Belton and Stewart (2002), who noted the following comments. In the first group, the values of alternatives reflect a preference order. These preferences are required to be consistent with a relatively strong set of axioms. Though in practice value measurement is not applied in such a rigid framework, these axioms: (a) “impose some form of discipline in the building up of preference models”; (b) “help the decision-makers to obtain greater understanding of their own values, and to justify their final decisions when required”; (c) “encourage explicit statements of acceptable tradeoffs between criteria”.

The second group presents methods for “situations in which decision makers may find it very difficult to express tradeoffs or importance weights, but may nevertheless be able to describe outcome scenarios, expressed in terms of satisfying aspirations or goals for each criterion”. Available courses of action (alternatives) are systematically eliminated until, in the view of the decision maker, a satisfactory level of performance for this criterion has been ensured. The process should be seen in a dynamic perspective. The decision maker should be able to backtrack the elimination process and cycle through it.

The outranking models focus “on pairwise evaluation of alternatives, identifying incomparabilities as well as assessing preferences and indifferences”. Preferences evolve “as part of the MCDA process within the context of the choices to be made”.

In light of the different MCDA methods and possible applications to support decision-making in natural resources

management, a question arises in terms of which method is preferred and should be selected. To answer this question, authors undertook comparisons between methods under similar planning situations. Duckstein et al. (1982) made the comparison in terms of: (1) consistency of results between methodologies, (2) robustness of results with respect to changes in parameter values, and (3) ease of computation. Hobbs et al. (1992) also made a comparison based on: (1) the degree of comfort the users feel in using the methods, (2) the confidence the users express in them, (3) the ability of the method to help users to understand the problem, (4) the ability of the methods to be valid, i.e. the resulting choices will be consistent with the actual preferences of the users and (5) the appropriateness and ease of use.

Kangas and Kangas (2002) argued, however, that methods and results are not necessarily directly comparable. Inconsistencies might arise because: (1) “the choice problem formulations do not reflect the same preference structures”, (2) “the ways in which preference information is processed vary between different methods”, and (3) “the methods interpret the criterion weights differently”. The authors also stress that it may be more important to compare the qualities of the methods themselves, than to compare the results obtained by different methods. Hobbs et al. (1992) also conclude that “careful tutoring and close collaboration between analyst and decision makers are more important than which method is adopted”.

3. Overview of the applications of MCDA in forestry and natural resources management

Over the last two decades, there have been a number of reviews published in the literature dealing with the application of MCDA to natural resources management problems. Examples of these reviews include Mendoza et al. (1986, 1987a), Romero and Rehman (1987), Tarp and Helles (1995), Hayashi (2000), Kangas et al. (2001a) and Steiguer et al. (2003). Books have also been published on applications such as Janssen (1991), Beinat and Nijkamp (1998), El-Swaify and Yakowitz (1998), Schmoldt et al. (2001) and Pukkala (2002). Similarly, a significant number of books have also surveyed MCDA methodologies with reference to some applications to natural resources management (e.g. Cohon, 1978; Hwang et al., 1979; Zeleny, 1984; Yoon and Hwang, 1995; Malczewski, 1999; Belton and Stewart, 2002).

In this paper, a problem-oriented overview is developed along three sub-sections: (1) nature and context of the problem; (2) type and complexity of the method; (3) number and type of decision makers. Authors and date of publication are common elements that can guide the readers across the different tables.

3.1. Nature and context of the problem

The references presented in Table 2 cover the range of MCDA methods from the 1970s until recently. They refer mainly to analyses carried out with real data, rather than simulated, and from different parts of the world, including applications in developing countries. Five of the publications

refer to the use of MCDA in the production of management plans for local entities and government (Malczewski et al., 1997; Andreoli and Tellarini, 2000; Siitonen et al., 2003; Kangas and Kangas, 2003; Phua and Minowa, 2005). This suggests that efforts have been made to promote MCDA as a tool to support decisions affecting policies and action plans for natural resources management under different ownership and management scenarios.

The diversity of models and methodological approaches that has been developed also has expanded the application of MCDA to a broad range of natural resources management problems. Strategic and operational forest management have been some of the most frequently analysed problems at diversified scales ranging from management units to watersheds and regions. Land-use planning has also been analysed including the integration of MCDA methods with Geographic Information Systems (Malczewski, 1999). MCDA has also been used to assess forest sustainability by using multi-criteria methods in the selection or assessment of management plans and management alternatives according to a set of sustainability indicators (e.g. Diaz-Balteiro and Romero, 2004).

Other applications of MCDA to decision problems in natural resources management include: (1) the selection of sites for networks of nature reserves (e.g. Snyder et al., 2004); (2) the integration of biodiversity conservation in management plans (e.g. Kangas and Kuusipalo, 1993); (3) wildlife management (e.g. Berbel and Zamora, 1995); (4) environmental conflict mitigation (e.g. Martin et al., 1996; Malczewski et al., 1997; Shields et al., 1999).

3.2. Type and complexity of the problem

Table 3 describes some of the most often used methods for MCDA. Under the first type of models (i.e. value measurement), the Analytic Hierarchy Process (Zahedi, 1986; Saaty, 2001) has been used to structure decision problems and to assess scores that translate DM's preferences into a prioritisation of either objectives or alternatives. Among the goal, aspiration, or reference level methods, goal programming is the most frequently applied and studied MCDA method. Thorough discussion of this method can be found in Mendoza (1987b) and Romero (1990). Some authors proposed an integration of the reference level methods with AHP, using the latter for assessing the weight of criteria in the former. This was the case with the integration of Modelling to Generate Alternatives and AHP by Mendoza and Sprouse (1989), of Goal Programming with AHP by Kangas and Pukkala (1992) and of Compromise programming with AHP by Phua and Minowa (2005). In terms of outranking methods, the most frequently applied are those of ELECTRE (Bella et al., 1996; Kangas et al., 2001b; Schmoldt et al., 2001) and PROMETHEE (Kangas et al., 2001b; Laukkanen et al., 2002).

There are many aspects of decision-making concerning natural resources management, and in particular forest management, that cannot be described adequately, or predicted deterministically, such as: future conditions of natural systems, states of interest that are inherently qualitative, risk, and human

Table 2

MCDA applications systematized according to country of application, type of data used, spatial scale, and nature and context of the problem

Reference	Country of application	Illustration example with simulated data	Illustration example with real data	Nature and context of the problem	Spatial scale
Steuer and Schuler (1978)	USA		X	Forest management planning	A 4047 ha sub unit of a national forest
Hallefjord and Jörnsten (1986)	Sweden		X	Multi-objective forest management planning	About 8000 ha stands aggregated by timber class
Mendoza (1987a)	Nigeria		X	Land use allocation in agro-forestry systems	A land unit
Mendoza et al. (1987a)	USA	X		Forest land planning	A 3200 ha forest
Mendoza et al. (1987b)	USA		X	Forest management and land allocation planning	Three management units with 18,211 ha
Bare and Mendoza (1988)	USA		X	Forest land management planning	A 102,629 ha forest area
Mendoza (1988)	USA		X	Forest management planning	A 102,387 ha forest
Mendoza and Sprouse (1989)	USA		X	Forest management planning	A 11,736 ha forest tract
Gong (1992)	Sweden	X		Multiple use forest management	A 10 ha forest
Kangas and Pukkala (1992)	Finland		X	Forest management planning	A 31.4 ha forest
Kangas (1992)	Finland		X	Strategic forest management planning	–
Kangas and Kuusipalo (1993)	Finland		X	Integrate biodiversity in strategic forest planning	A 320 ha forest
Mendoza et al. (1993)	USA		X	Forest management planning	A national forest
Kangas (1994)	Finland	X		Strategic forest management planning	A recreation area
Eskandari et al. (1995)	USA		X	Watershed management	Four watersheds from 546 to 121 ha
Chang et al. (1995)	Taiwan		X	Watershed land resource allocation	A watershed
Berbel and Zamora (1995)	Spain		X	Wildlife management	A 3600 ha forest
Alho et al. (1996)	Finland		X	Analysis of forest plans in terms of habitat suitability for black grouse	A 117 ha forest
Bella et al. (1996)	USA		X	Water allocation conflict	A river basin
Martin et al. (1996)	USA		X	Dealing with conflict over oil and gas interests in a national forest	A national forest
Antoine et al. (1997)	Kenya		X	Land resources appraisal	A district
Pukkala and Miina (1997)	Finland		X	Multi-objective optimisation of stand management	A stand
Malczewski et al. (1997)	Mexico		X	Environmental conflict analysis	A region
Bantayan and Bishop (1998)	Philippines		X	Land-use allocation	A forest reserve
d'Angelo et al. (1998)	USA		X	Selection of the best forestry treatment method	Four watersheds
McDaniels and Thomas (1999)	Canada		X	Selection of the best land use	An undeveloped area of publicly owned suburban land
Pukkala (1998)	Finland	X		Forest management planning	A 50 ha forest holding
Shields et al. (1999)	USA		X	Conflict resolution on oil and gas leasing on a national forest	A national forest
Prato (2000)	USA	X		Watershed management planning towards sustainability	National forest, national park, wildlife refuge, etc.
Prato (2000)	USA	X		Watershed management planning towards sustainability	Farm, ranch, forest
Andreoli and Tellarini (2000)	Italy		X	Assessment of farm sustainability	A region
Hajkowicz et al. (2000)	Australia		X	Evaluation of environmental projects	–
Kangas et al. (2000)	Finland		X	Selection of a tactical forest plan	A 2024 ha forest estate
Martin et al. (2000)	USA			Ranking forest management alternatives	A 755,873 ha forest
Reynolds and Peets (2001)	USA		X	Prioritise watersheds and reaches for protection and restoration	A watershed system
Kangas et al. (2001b)	Finland		X	Strategic natural resources planning	A region
Nhantumbo et al. (2001)	Mozambique		X	Management of the miombo land	A district
Pesonen et al. (2001)	Finland			Strategic forest planning	A region
Vacik and Lexer (2001)	Austria		X	Management of protection forest for sustained yield of water resources	A 2294 ha forest

Table 2 (Continued)

Reference	Country of application	Illustration example with simulated data	Illustration example with real data	Nature and context of the problem	Spatial scale
Laukkanen et al. (2002)	Finland		X	Forest management planning	A 30 ha forest holding
Memtsas (2003)	Greece		X	Reserve selection	A region
Oliveira et al. (2003)	Brazil		X	Land allocation	A 2000 ha farm
Siitonen et al. (2003)	Finland		X	Selection of forest reserves	A 10000 ha landscape
Ananda and Herath (2003a)	Australia		X	Regional forest planning	A region
Ananda and Herath (2003b)	Australia	X		Regional forest planning	A region
Kangas and Kangas (2003)	Finland		X	Forest management planning	A 30 ha forest holding
Herath (2004)	Australia		X	Wetland management	A 180 ha wetland
Kangas et al. (2003a)	Finland		X	Forest management planning	A 30 ha forest holding
Kangas et al. (2003b)	Finland		X	Selection of a tactical forest plan	A 2024 h forest estate
Agrell et al. (2004)	Kenya		X	Land use planning	A region
Snyder et al. (2004)	Australia		X	Reserve selection	Land holdings and land systems
Stewart et al. (2004)	The Netherlands		X	Land use planning	A region
Diaz-Balteiro and Romero (2004)	Spain		X	Selecting forest management plans according to sustainability indicators	A 1156 ha public forest
Laukkanen et al. (2004)	Finland		X	Forest management planning	A 128 ha forest
Laukkanen et al. (2005)	Finland		X	Selection of a tactical forest management plan	A 30 ha forest holding
Pasanen et al. (2005)	Finland	X		Selection of a forest management plan	A forest property
Phua and Minowa (2005)	Malaysia		X	Forest conservation planning	A landscape

subjectivity in judgements (Mendoza et al., 1993; d'Angelo et al., 1998; Pukkala, 1998; Malczewski, 1999; Ananda and Herath, 2003b; Kangas and Kangas, 2004). All these situations contribute to uncertainty in decision-making, which are often not considered because of data unavailability and costs (Malczewski, 1999). However, accommodating uncertainty is important in decision-making because it has the potential to lead to inadequately defined alternatives or plans (Kangas et al., 2000). Kangas and Kangas (2004) provide an overview of the different sources of uncertainty and describe different methodologies that can be used to deal with uncertainty in decision-making within the framework of forest-related problems.

In this paper, applications that take explicitly account uncertainty are described in Table 3, along with the methodological approaches used. The review covers the most common approaches to uncertainty that have been applied in natural resources management (see Kangas and Kangas, 2004). In situations where uncertainty is mainly due to randomness, the methods used are probability-based. This is the case, for example, of Gong (1992) who used a Markov process to generate criteria values under certain alternatives. Eskandari et al. (1995) made use of a probability mass function to model payoff values in order to support decisions in the selection of management plans. In what concerns uncertainty in preferences, Prato (2000) demonstrates the use of Bayesian theory integrated into a stochastic programming model to identify the most efficient management plans for a site/landscape, based on the data available and the prior beliefs. A stochastic approach was also used by Alho et al. (1996) to assess the uncertainty in AHP results concerning the ecological effects of forest plans. Regression was then used to analyse the variation in the views of the various experts, and also the internal inconsistencies of individual views. Presented as an alternative to the calculation

of a consistency index that is usually incorporated into AHP analysis, this approach derives quantitative estimates of the uncertainties based on the modelling of variance components.

Several authors have proposed probability-based approaches to deal with uncertainty. For example, probability-based utility theory approaches, including uncertainty in decision makers' preference structure have been proposed Martin et al. (1996), Pukkala and Miina (1997), Pukkala (1998), Andreoli and Tellarini (2000) and Vacik and Lexer (2001). Similarly, Kangas and Kangas (2003) and Kangas et al. (2003a,b) used a method called stochastic multicriteria acceptance analysis (SMAA) that attempts to incorporate both the uncertainty derived from the stochastic nature of different criteria and the inconsistency in the preference structure.

There are cases where the uncertainty may be due to imprecision. Probability theory is no longer useful to deal with this source of uncertainty since the outcome of the decision is no longer "true or false" but rather ambiguous (Malczewski, 1999). In this case, some authors have proposed fuzzy set theory and fuzzy logic (Mendoza and Sprouse, 1989; Mendoza et al., 1993; Reynolds and Peets, 2001).

With respect to uncertainty related to the structure of preferences, a deterministic approach commonly used to reduce uncertainty in the judgements concerning the weights of the criteria, is sensitivity analysis. Examples of the application of this method can be found in Kangas et al. (2000) and Ananda and Herath (2003b). Other deterministic methods that have been widely used to deal with uncertain judgements upon different alternatives are the outranking methods, ELECTRE and PROMETHEE. Kangas and Kangas (2002) describe these methods as indicating the degree of dominance of one alternative over another. They enable the utilization of incomplete value information and judgements on ordinal measurement scale. Supposedly, the uncertainty concerning the

Table 3
MCDA applications systematized by model type based on classification suggested by Belton and Stewart (2002)

Reference	Type of model			Number of criteria/number of alternatives	Nature of the criteria	Deals explicitly with uncertainty?	
	Value measurement models	Goal, aspiration or reference level models	Outranking models			Source	Method used
Steuer and Schuler (1978)		Combination of linear programming with vector maximum techniques		5/8	1, timber production; 2, dispersed recreation; 3, hunting forest species; 4, hunting open land species; 5, grazing	No	No
Hallefjord and Jörnsten (1986)		Belenson–Kapur procedure (combination of weighting methods with two person zero sum game) and entropy reference point method		3 and 7/large	(A) 1, variation in sawlog drain; 2, variation in total drain; 3, sawlog drain in period 1. (B) 1, variation in sawlog drain to be minimized; 2, variation in total drain to be minimized; 3, sawlog drain in period 1 to be kept at a “reasonable” level; 4, thinning period 1 to be minimized; 5, thinning period 2 to be minimized; 6, thinning period 3 to be minimized; 7, sawlog drain periods 1–7 to be maximized	No	No
Mendoza (1987a)		Modelling to generate alternatives (MGA)		6/large	1, economic return; 2, operational costs; 3, total area allocated; 4, hired labor; 5, farmer’s labor in the first season; 6, farmers labor in the second season	No	No
Mendoza et al. (1987a)		Weighting method, goal programming, STEM method. MGA		2/large	1, present net worth of each management regime; 2, black walnut timber volume	No	No
Mendoza et al. (1987b)		Modelling to generate alternatives		5/large (constrained by HSJ algorithm)	1, timber yield; 2, forage production; 3, developed recreation; 4, dispersed recreation; 5, water production	No	No
Bare and Mendoza (1988)		STEM method		3/large	1, timber harvest plus ending inventory volume; 2, number of animals for five “indicator” species; 3, number of animals for “indicator” species 4	No	No
Mendoza (1988)		Modelling to generate alternatives		7/large (constrained by HSJ algorithm)	1, total return from timber management; 2–7, total utility index for wildlife species k ($k = 1, \dots, 6$)	No	No
Mendoza and Sprouse (1989)		Modelling to generate alternatives, with use of AHP to prioritise alternatives		3/1	1, discounted net revenue; 2, area suitable for wildlife habitat; 3, area suitable for non-motorized semi-primitive recreation	Aspired objective values	Fuzzy logic
Gong (1992)		Multi-objective dynamic programming		2/large	1, revenue from timber harvest; 2, satisfaction from the standing trees	Stochastic criteria values	Markov decision process
Kangas and Pukkala (1992)		Goal programming, with use of AHP to assess goals relative importance		4/large	1, total volume after 20 years; 2, annual volume increment after 20 years; 3, net income during the first 10-year period; 4, net income during the second 10-year period	No	No
Kangas (1992)	A priority function created with AHP to prioritise alternatives generated with LP concerning wood production			3/6	1, wood production; 2, forest landscape; 3, game management	No	No

Kangas and Kuusipalo (1993)	A priority function created with AHP		5/6	1, net income from timber sales; 2, value of the growing stock at the end of the planning period; 3, area to be regenerated during the planning period; 4, total volume of broad-leaved trees at the end of the planning period; 5, mean amenity value of the forest stands at the end of the planning period	No	No	
Mendoza et al. (1993)		Fuzzy multiple objective linear programming	4/large	1, net present value; 2, sediment yield; 3, timber production; 4, forest production	Aspired objective values	Fuzzy logic	
Kangas (1994)	A priority function created with AHP		4/6	1, priority for research activities; 2, priority for recreation activities; 3, priority for conservational considerations; 4, priority for wood production	No	No	
Eskandari et al. (1995)		Distance-based discrete multi-objective programming	14/4	1, stream flow; 2, sediment yield; 3, deer habitat use; 4, elk habitat use; 5, pigmy nuthatch habitat use; 6, violet-green swallow habitat use; 7, cavity nesters habitat use; 8, aesthetics; 9, total herbage production; 10, perennial grass production; 11, livestock carrying capacity; 12, management costs; 13, growth of merchantable wood; 14, growing stock	Preference structure	Modelling of payoff values with probability mass function	
Chang et al. (1995)		Compromise programming and multi-objective simplex method	6/large	1, total discharge of phosphorus, 2, total discharge of nitrogen; 3, total discharge of biological oxygen demanding load; 4, total discharge of sediment yield; 5, employment level by land development; 6, income by land development	No	No	
Berbel and Zamora (1995)		Lexicographic goal programming	2/large	1, economic income; 2, number of roe deer at the end of the planning period	No	No	
Alho et al. (1996)	A priority function created with AHP		5/10	1, total volume in thousands of cubic metres; 2, share of deciduous species as a percentage of volume; 3, index of scenic beauty; 4, length of boundaries of distinct forest stands in kilometres; 5, proportion of old tree stands as a percentage	Preference structure	Modelling of the variance of experts' views and inconsistency in individual views when finding the mean estimate of preferences	
Bella et al. (1996)		Compromise programming	Electre III	18/30	1, operation, maintenance and allocation costs; 2, damage losses; 3, benefit for flood control, recreation, water supply and water quality; 4, scenic reaches; 5, social impact; 6, number of species by reach; 7, catches per hour; 8, temperature; 9, water quality; 10, recreation in visitor-days; 11, percent protection; 12, development possibility; 13, tonnes of sediment produced; 14, capacity exceedance; 15, equity of allocation; 16, conjunctive use possibility; 17, allocation subsidy; 18, flora and fauna	Preference structure	Pseudo-criteria
Martin et al. (1996)	Voting methods and utility theory		It does not apply/7		Preference structure	Utility theory	

Table 3 (Continued)

Reference	Type of model			Number of criteria/number of alternatives	Nature of the criteria	Deals explicitly with uncertainty?	
	Value measurement models	Goal, aspiration or reference level models	Outranking models			Source	Method used
Antoine et al. (1997)		Aspiration-reservation-based decision support		10/large	1, food output; 2, net revenue; 3, production costs; 4, gross value of output; 5, arable land use; 6, area harvested; 7, food output in bad years; 8, total erosion; 9, self-sufficient ration; 10, erosion at the level of agro-ecological cells	No	No
Pukkala and Miina (1997)	Additive utility function optimized by use of a non-linear programming algorithm, integrated with scenario technique			3/large	1, present value on net incomes; 2, discounted felling value of growing stock; 3, discounted value of a scenic beauty score of the stand	Risk, preference structure	Scenario technique, utility theory
Malczewski et al. (1997)		Integer programming, with the use of AHP to assess criteria weights		21/3	1, water supply for agriculture; 2, accessibility to US markets; 3, cattle population; 4, accessibility to transportation; 5, vegetation types proper for cattle; 6, water supply for tourism; 7, accessibility to water; 8, biodiversity conservation; 9, forest SPP coverage; 10, game population; 11, tourist activity; 12, industrial park areas; 13, accessibility to transportation; 14, accessibility to infrastructures; 15, water supply for industrial and urban development; 16, accessibility to hunting areas; 17, tourist services; 18, sport fishing services; 19, water supply for tourism; 20, tourist water pollution; 21, catchment areas	No	No
Bantayan and Bishop (1998)	A priority function created with AHP			7/4	1, soil stability; 2, recreation; 3, employment; 4, sustainable/potable water, 5, food production; 6, education and research; 7, pollution abatement	No	No
d'Angelo et al. (1998)	Social choice theory			14 (when it applies and it depends on the stakeholders group)/4	1, stream flow; 2, sediment; 3, deer; 4, elk; 5, pygmy nuthatch; 6, violet-green swallow; 7, cavity nesters; 8, herbage production; 9, grass production; 10, carrying capacity; 11, merchantable volume; 12, growth; 13, aesthetics; 14, management costs	Preference structure	Social choice theory
Pukkala (1998)	Multi-attribute utility theory with a heuristic optimisation algorithm			5/7	1, net income during first planning period; 2, net income during second planning period; 3, volume after 2 years; 4, recreation score after 20 years	Risk, reference structure	Scenario technique, utility theory
McDaniels and Thomas (1999)	A structured value referendum with approval voting			21/4	Several organized into the following aspects: 1, environment; 2, social; 3, economic; 4, municipal land use planning	Preferences structure	Approval voting

Shields et al. (1999)	Utility theory combined with voting methods		10 grouped in 3 groups (social, economic and environmental)/7	1, health and safety; 2, community stability; 3, recreation and tourism; 4, commodity access; 5, local economic impact; 6, national economic impacts; 7, species impacts; 8, ecosystem impacts; 9, water quality; 10, air quality	No	No
Kangas et al. (2000)	A priority function created with AHP applied to optimal alternatives generated by MONSU		3/10	1, ecological network; 2, net revenues; 3, volume of the growing stock	Preference structure	Sensitivity analysis of weights, Bayesian approach to pairwise comparisons
Prato (2000)	Utility theory	e-Constraint method	7/2	1, timber cut; 2, income; 3, employment; 4, tax revenues; 5, recreational values; 6, water quality; 7, biodiversity	Stochastic attributes, preference structure	Normal distribution assumed, Bayes theorem, utility theory
Prato (2000)	Utility theory	e-Constraint method	3/2	1, harvest rate; 2, income; 3, costs	Stochastic attributes, preference structure	Normal distribution assumed, Bayes theorem
Andreoli and Tellarini (2000)	Utility theory		Many organized in six groups/all the farms of a region	1, environment; 2, ecology; 3, economy; 4, sociology; 5, psychology; 6, physiognomy/cultural geography	Preference structure	Utility theory
Hajkowicz et al. (2000)	Utility theory with the following weighting methods: fixed point scoring, rating, ordinal ranking, a graphical method		6/5 projects	1, agricultural profitability; 2, enhance natural ecosystems; 3, improve land capability; 4, community benefit; 5, improve attitudes and education; 6, minimize risk	No	No
Martin et al. (2000)	Attribute value function with the swing weighting method		3/6	1, watershed improvement; 2, dispersed recreation; 3, species protection; 4, acres available for leasable development	No	No
Reynolds and Peets (2001)	A priority function created with AHP		3 for watersheds and 4 for reaches/8 watersheds and 85 stream reaches	(A) 1, watershed condition; 2, feasibility of restoration; 3, efficacy of restoration. (B) 1, reach condition; 2, watershed restoration priority; 3, reach-level feasibility; 4, reach-level efficacy	Preference structure	Fuzzy logic
Kangas et al. (2001b)		Electre III and Promethee II	17/4	1, area of commercial forests; 2, FPS's financial surplus; 3, change in timber volume in commercial forests; 4, direct effect on employment; 5, indirect effect on employment; 6, FPS's turnover; 7, area of recreational forest; 8, area of commercial forest with recreational values; 9, recreation value index; 10, area of clearcut forest stands; 11, area of fertilised forests; 12, area of ditch network maintenance; 13, conserved area; 14, area of commercial forests with conservation values; 15, change in dead wood volume; 16, change in the area of old forests; 17, change in the volume of hardwood	Preference structure	Pseudo-criteria

Table 3 (Continued)

Reference	Type of model			Number of criteria/number of alternatives	Nature of the criteria	Deals explicitly with uncertainty?	
	Value measurement models	Goal, aspiration or reference level models	Outranking models			Source	Method used
Nhantumbo et al. (2001)		Goal programming		7/large	1, area to be protected as national park and as reserves; 2, area that can be harvested for fuelwood and construction timber; 3, annual allowable cut for industrial roundwood; 4, area for tourism; 5, consumption of firewood per year; 6, is the consumption of poles for housing; 7, demand of wild fruits and animals	No	No
Pesonen et al. (2001)	A'WOT			It does not apply/4 5/49	It does not apply	No	No
Vacik and Lexer (2001)	Utility theory				1, water production; 2, timber production; 3, conservation of biodiversity; 4, recreation; 5, protection against rockfall and avalanches	Criteria values, preference structure	Expert knowledge, utility theory
Laukkanen et al. (2002)	Multi-criteria approval with AHP			5/20	1, net incomes; 2, biodiversity; 3, monetary value of the timber production; 4, scenic beauty of the forest landscape; 5, wild berry yield	Preference structure	Multi-criteria approval
Memtsas (2003)	Simple multi-attribute rating technique (SMART)	Geometric methods-based on distance		4/large	1, number of species represented; 2, sum of the species rarity scores of the species represented; 3, sum of the cell richness scores; 4, sum of the cell rarity scores	No	No
Oliveira et al. (2003)		Goal programming		8/large	1, wood harvest (pine); 2, wood harvest (araucaria); 3, leaves of erva-mate harvest; 4, tourism; 5, pasture; 6, maintenance of employment; 7, increase in the diversity of the flora; 8, increase in the diversity of the fauna	No	No
Siitonen et al. (2003)		Greedy heuristic algorithm		17/large	1, economic expenditure; 2, continuous area and connectivity objectives; . . . and several spatial and non-spatial objectives	No	No
Ananda and Herath (2003a)	Multi-attribute value theory			3/3	1, old-growth forest conservation; 2, hardwood timber production; 3, recreation intensity	No	No
Ananda and Herath (2003b)	A priority function created with AHP			3/5	1, timber production; 2, biodiversity conservation; 3, recreation	Preference structure, risk	Sensitivity analysis, risk preference functions
Kangas and Kangas (2003)	Multi-criteria approval and stochastic multi-criteria acceptability analysis with ordinal criteria (SMAA-O)			5/20	1, present value of net incomes within the planning horizon; 2, estimated value of future timber production in the end of the planning horizon; 3, blueberry yield; 4, scenic beauty; 5, biodiversity	Criteria values, preference structure	Joint probability distribution, weights randomly chosen from appropriate distributions, multi-criteria approval

Herath (2004)	A priority function created with AHP		5/3	1, conservation value; 2, business investment; 3, recreation visitor-days; 4, extent of river red gum; 5, number of bird species	No	No
Kangas et al. (2003a)	Hybrid method of the stochastic multi-criteria acceptability analysis with ordinal criteria (SMAA-O) and SWOT (S-O-S)		16/6	Organized as SWOT factors: 1, good hunting possibilities; 2, excellent hiking possibilities; 3, possessing share yields income and recreational possibilities; 4, future timber cutting possibilities in own forests; 5, great distance from current residences; 6, cottage needs repair; 7, cottage is poorly provided as regards facilities; 8, costs of maintenance; 9, repairing will increase usage; 10, additional incomes from renting the cottage to holidaymakers; 11, new facilities will improve the quality of holidays; 12, selling or not repairing the cottage would mean income or saved money; 13, cuttings could spoil the scenery and decrease recreational values; 14, social interaction between partners will fade if the cottage is sold; 15, repairing can cost more than expected; 16, benefits from the forest will be lost	Criteria values, preference structure	Joint probability distribution, weights randomly chosen from appropriate distributions, multi-criteria approval
Kangas et al. (2003b)	Stochastic multi-criteria acceptability analysis with ordinal criteria (SMAA-O)		5/10	1, net income from timber cuttings during the planning period; 2, total volume of the unreserved forest stands after the planning period; 3, recreational value; 4, viability of rare species; 5, risks of environmental hazards to the riparian areas	Criteria values, preference structure	Joint probability distribution converted into stochastic cardinal data, weights randomly chosen from appropriate distributions
Agrell et al. (2004)	Linear programming, interactive weighted Tchebycheff Procedure		10/large	Related to sustainability, economic, environmental and social feasibility over different time horizons	Risk, preference structure	Risk constraints, interactive adjustment of weights
Snyder et al. (2004)	Weighting method		2/large	1, total area of selected sites; 2, total number of covered land systems	Preference structure	Interactive adjustment of weights
Stewart et al. (2004)	Genetic algorithm applied to goal programming/reference point approach		3/large	1, number of clusters for each land use; 2, relative magnitude of the largest cluster for each land use; 3, compactness of land uses	Uncertainty in preference structure	Multi-objective weighting (sensitivity analysis)
Diaz-Balteiro and Romero (2004)	Goal programming		11/14	Indicators of sustainability: 1, net present value; 2, veneer volume; 3, final inventory; 4, even flow volume; 5, regulation; 6, uncut area; 7, mixed stands cutting area; 8, ratio harvest volume/stand growth; 9, average rotation age; 10, net carbon; 11, mean cutting area	No	No
Laukkanen et al. (2004)	Voting theory		7/9	1, clearcut area; 2, harvesting volume; 3, capercaillie habitat needs; 4, harvesting income; 5, nature conservation; 6, recreation and landscape; 7, local employment	Preference structure	Social choice

Table 3 (Continued)

Reference	Type of model	Goal, aspiration or reference level models	Outranking models	Number of criteria/number of alternatives	Nature of the criteria	Deals explicitly with uncertainty?	
						Source	Method used
Laukkanen et al. (2005)	Multi-criteria approval			5/30	1, net harvesting income; 2, effects on nature conservation values; 3, effects on recreational values; 4, expectation of logging damage; 5, favouring local contractors	Preference structure	Social choice
Pasanen et al. (2005)	Multi-criteria acceptability voting			5/5	1, volume; 2, net income in period 1; 3, net income in period 2; 4, increment; 5, cutting removal	Preference structure	Social choice
Phua and Minowa (2005)		Compromise programming, with use of AHP to assess weights		2/it does not apply	1, biodiversity conservation; 2, soil and water resources	No	No

preferences and also the criterion values is dealt with using pseudo-criteria. This means that two thresholds, namely indifference and preference thresholds, are defined. The indifference threshold for a criterion is a difference between the performances of two alternatives concerning the criterion, beneath which the decision maker is indifferent between the two management alternatives. The preference threshold is the difference above which the decision maker strongly prefers one management alternative above the other. Between these two thresholds there is the zone of weak preference, where the decision maker hesitates. Examples of application of these methods can be found in [Bella et al. \(1996\)](#) and [Kangas et al. \(2001b\)](#). In spite of efficiently dealing with uncertainty concerning the decision rules, [Rogers and Bruen \(1998\)](#) pointed out that these methods might be considered too subjective and unreliable for applications such as environmental assessments. The authors suggest, specifically for ELECTRE III, a new method that involves a “more comprehensive approach for specifying realistic limits for the thresholds where both criterion error/uncertainty and human sensitivity to differing levels of the criterion are taken into account”.

3.3. Number and type of decision makers

Table 4 shows an overview of the way decision makers and preferences have been taken into account in MCDA applications to natural resources management. The classification based on the way preferences were included was inspired by the three general approaches to solving MCDA problems suggested by [Korhonen et al. \(1992\)](#), particularly in terms of the moment of the decision maker (DM) intervention. The a priori inclusion is when modelling of the preferences is the starting point of the modelling process. The interactive articulation of preferences assumes that the answer of the DM to specific questions leads the solution process towards the “most” preferred one. Finally, the *posterior* articulation of preferences involves the generation of ‘non-dominated’ solutions, which are presented to the DM for evaluation. The overview in Table 4 presents a wide range of examples of application of the three approaches.

Group multi-criteria decision-making gained some prominence in the 1990s. Earlier, most of the applications assumed the existence of a single decision maker, usually the owner of the land unit or even the analyst. More recently, applications attempt to have all interests represented and, therefore, consider the different groups of stakeholders who hold interest on the management of natural resources, such as conservationists, hunters, local residents, industry and recreationists.

4. MCDA methods for collaborative planning and decision-making

Public participation through involvement of local communities in forest management decision-making gained relevance and wide acceptance following international discussions on sustainable development that ensued after the UN Conference on Environment and Development in Rio ([UNCED, 1992](#)).

Table 4

MCDA applications systematized according preferences, number, and type of decision makers involved

Reference	Preferences included	Single DM	Group decision	Type of DM
Steuer and Schuler (1978)	Interactively		X	Planning team
Hallefjord and Jörnsten (1986)	A priori	X		State
Mendoza (1987a)	Posterior	X		State
Mendoza et al. (1987a)	A priori and interactively	X		Analyst
Mendoza et al. (1987b)	Posterior	X		Analyst
Bare and Mendoza (1988)	Interactively	X		State
Mendoza (1988)	Posterior	X		Analyst
Mendoza and Sprouse (1989)	Posterior	X		Analyst
Gong (1992)	Posterior	X		Forest owner
Kangas and Pukkala (1992)	A priori	X		Expert
Kangas (1992)	Posterior	X		Manager
Kangas and Kuusipalo (1993)	Posterior		X	Experts
Mendoza et al. (1993)	Posterior		X	Expert
Kangas (1994)	Posterior		X	Hikers, local inhabitants, nature conservationists, tourism entrepreneurs
Eskandari et al. (1995)	A priori		X	Experts representing water users, livestock producers, foresters, environmentalists, land use planners
Chang et al. (1995)	A priori	X		Analyst
Berbel and Zamora (1995)	Interactively	X		Analyst
Alho et al. (1996)	A posterior		X	Experts representing wildlife researchers, hunters, biologists, and foresters
Bella et al. (1996)	A priori		X	Experts
Martin et al. (1996)	Posterior		X	1, oil company; 2, environmental organizations; 3, local tourist industry; 4, local timber industry; 5, local retail/wholesale merchants; 6, local government units; 7, federal government
Antoine et al. (1997)	Interactively	X		Analyst
Pukkala and Miina (1997)	A priori (objectives, time and risk)	X		Expert
Malczewski et al. (1997)	Posterior		X	The ones that support: 1, agriculture; 2, cattle ranching; 3, bioconservation and forestry; 4, hunting; 5, industry and urban development; 6, tourism and sport fishing; 7, water catchment
Bantayan and Bishop (1998)	Posterior		X	–
d'Angelo et al. (1998)	Posterior		X	1, water users; 2, wildlife advocates; 3, livestock producers; 4, wood producers; 5, environmentalists; 6, managers
McDaniels and Thomas (1999)	Posterior		X	200 randomly selected adults
Pukkala (1998)	A priori	X		Analyst
Shields et al. (1999)	A priori		X	Oil company, environmental organization, local tourism industry, local timber industry, local retail/wholesale merchants, local government units, federal government
Kangas et al. (2000)	Interactively	X		An expert in ecology
Prato (2000)	Interactively	X		Public agency
Prato (2000)	Interactively		X	Local stakeholders
Andreoli and Tellarini (2000)	A priori		X	Stakeholders
Hajkowicz et al. (2000)	A priori		X	1, primary producer; 2, extension officer; 3, environmental conservation representative; 4, governmental natural resources manager; 5, technical expert or scientist; 6, elected representative of local government
Martin et al. (2000)	A priori		X	1, conservationists; 2, stakeholder; 3, a mountain bike interest group
Reynolds and Peets (2001)	Posterior	X		Expert
Kangas et al. (2001b)	A priori		X	Interest groups and the public
Nhantumbo et al. (2001)	A priori		X	1, private sector; 2, state; 3, local communities
Pesonen et al. (2001)	Posterior		X	Managers
Vacik and Lexer (2001)	Posterior		X	Experts
Laukkanen et al. (2002)	A priori		X	–
Memtsas (2003)	A priori	X		Analyst
Oliveira et al. (2003)	A priori		X	Stakeholders

Table 4 (Continued)

Reference	Preferences included	Single DM	Group decision	Type of DM
Siitonen et al. (2003)	A priori	X		Analyst
Ananda and Herath (2003a)	A priori		X	1, timber industry; 2, environmentalists; 3, farmers; 4, recreationists; 5, tour operators
Ananda and Herath (2003b)	Posterior		X	1, timber industry; 2, environmentalists; 3, farmers; 4, recreationists; 5, tour operators
Kangas and Kangas (2003)	A priori		X	Forest owners
Herath (2004)	Posterior		X	1, business group; 2, conservation group; 3, recreation users
Kangas et al. (2003a)	A priori		X	Forest owners
Kangas et al. (2003b)	Interactively		X	Not specified
Agrell et al. (2004)	Interactively	X		Expert
Snyder et al. (2004)	Posterior	X		Analyst
Stewart et al. (2004)	A priori	X		Analyst
Diaz-Balteiro and Romero (2004)	A priori	X		Analyst
Laukkanen et al. (2004)	Posterior		X	1, administration; 2, local residents; 3, hunters; 4, timber buyers; 5, conservationists; three groups of experts representing local forest organizations
Laukkanen et al. (2005)	Posterior		X	Three forest owners
Pasanen et al. (2005)	Interactively		X	A group of 20 non-industrial private forest owners
Phua and Minowa (2005)	A priori		X	Conservationists and neutral DM

Increasingly, decisions about how forests and other natural resources should be managed have become more collaborative instead of being within the exclusive domain of experts, resource managers, and other professionals.

In recognition of its importance, the [International Labour Office \(2000\)](#) has stated the following as potential purposes of public participation in forestry: (1) increase awareness of forestry issues and mutual recognition of interests, (2) gather information and enhance knowledge on forests and their users, (3) improve provision of multiple forest goods and services, (4) stimulate involvement in decision-making and/or implementation processes, (5) enhance acceptance of forest policies, plans and operations, (6) increase transparency and accountability of decision-making, and (7) identify and manage conflicts and problems together, in a fair and equitable way. Consequently, because of these developments, citizen involvement is now widely accepted, and in most cases highly recommended ([Wondolleck et al., 1996](#)). Moreover, public participation is engendered by two aspects of social sustainability that must be taken into account in forest planning; namely, the need to maintain the social functions of the forest, and the increasing awareness and demand from the citizenry for fair and transparent processes in both the development of forest plans and the evaluation of management alternatives ([Pukkala, 2002](#)). This is particularly relevant in forestry because there are usually many objectives at stake and many interests involved that are also likely in conflict.

In view of its participatory nature, forest management methods must necessarily provide for mechanisms to carry out group, or participatory, decision-making. The individuals, along with other members of a community, usually have different expectations and possibly conflicting goals, which will certainly increase the complexity of decision-making in natural resources management.

Before expounding on the methodological aspects of group decision-making, the concept itself requires some clarification. As mentioned before, group decision is called for when many interests and potentially conflicting goals are involved. Group decision is, therefore, more a problem about consistency of the group's goals, preferences and beliefs than with the number of people involved, as pointed by [Malczewski \(1999\)](#). If a single structure of beliefs and interests can be assumed, then group decision-making can be treated in the same manner as individual decision-making, regardless of the number of people actually involved. Between these two extremes there is a gradient of decision situations as illustrated in [Fig. 1](#).

Methodological adaptations of MCDA to group decision-making have evolved in three main aspects of a collaborative decision process: (1) identification of participants; (2) facilitation of participant's contributions with information; (3) aggregation of individual choices and decisions. Unless it is made explicit in the decision problem, the first aspect involves the identification of participants, which should be a clear and transparent process ([Buchy and Hoverman, 2000](#)). As [Ravnborg and Westermann \(2002\)](#) pointed, it should also be an "actor-oriented and social constructivist" approach that drives itself away from a mistaken perception of a homogeneous community that many participatory methods assume.

Readers are referred to [Lahdelma et al. \(2000\)](#) for a comprehensive characterization of participants' typologies. In most studies, the selection of the stakeholders is done by the analyst based on surveys and available information. Based on previous published work, [Herath \(2004\)](#) systematizes the selection methods in two groups: (a) identification through reputation, focus group or demographic groups or demographic analysis ([Grimble and Chan, 1995](#)); or (b) interactive identification, where previously unknown stakeholders reveal others ([Harrison and Quershi, 2000](#)). More formal frameworks

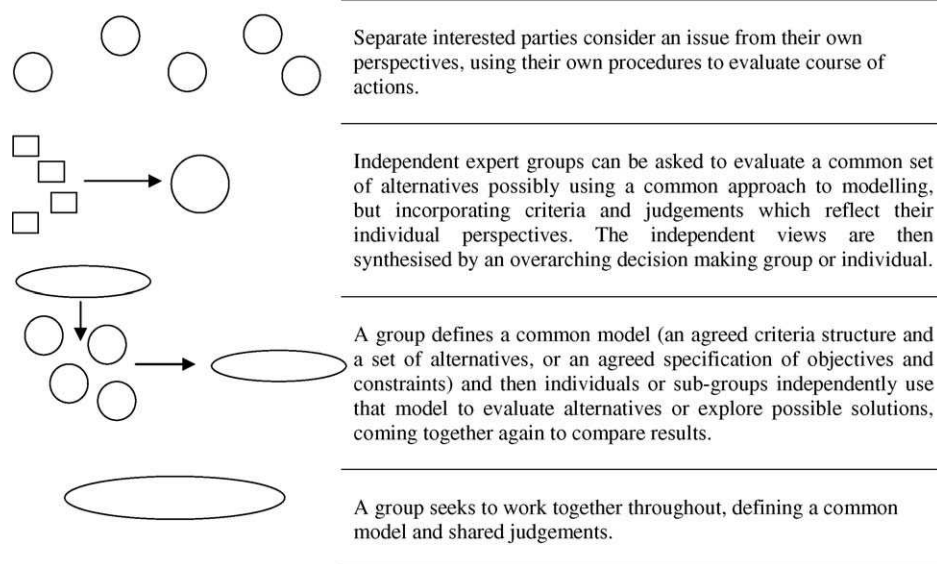


Fig. 1. Gradient of approaches to individual and group decision-making (Belton and Stewart, 2002).

for stakeholders' selection have been suggested by Grimble and Wellard (1997) and Colfer et al. (1999).

After identifying the decision makers, the next step is to facilitate their contribution with information that ultimately leads to the definition of the decision problem (management options, objectives and goals). The contributions under this aspect of MCDA are generally alternative-driven in the sense that decision makers are faced with a set of previously defined alternatives, hence, decision makers contribute only with their preferences by providing judgements on scores, criteria weights and attributes estimates (Keeney, 1992; Mendoza, 1995). This is done through elicitation methods that can be conducted either individually in a passive way, or collectively in a constructive way. Examples of both methods can be found in Hwang and Lin (1987) and Coughlan and Armour (1992). The Delphi method is an example of a passive method (e.g. Mendoza and Prabhu, 2000). This group of methods lack the advantage of decision makers being able to share and hear different opinions through open dialogue. Supporters of the constructive elicitation methods, such as the Focus group (e.g. McDaniels and Roessler, 1998), argue that these methods offer several advantages of an open discussion such as the consistency in the information obtained, and a progressively better definition of the preferences (McDaniels and Roessler, 1998; Laukkanen et al., 2002).

Elicitation methods have benefited greatly from the development of applied software designed as tools to motivate and support public participation. One of the most promising tools is the internet technology and accompanying development tools that allow dispersed and asynchronous working (Belton and Stewart, 2002). Thomson (2000), for example, demonstrates its use in the elicitation and representation of traditional knowledge for use in forest management. The design of computer assisted visualization tools has also been shown to have great potential in assisting elicitation methods (Bell, 2001).

Beyond the generally unstructured sets of information on preferences obtained from the decision makers, there is a need to make choices and decisions that would be considered satisfactory by the group. Thus, individual viewpoints and information gathered ought to be synthesised—the third methodological aspect of group decision that has to be considered. The synthesis of individual preferences can be done assuming either equal or unequal weights for stakeholders (Herath, 2004).

Belton and Pictet (1997) proposed a framework for this purpose where each judgement may be determined, namely by: (1) sharing: to obtain consensus through discussion; (2) aggregating: a process where differences are reduced analytically without discussion, for example by calculating geometric mean; (3) comparing: to reach consensus based on negotiation of individual results. Differences are acknowledged, but not reduced unless they mitigate against overall consensus.

Aggregation of individual judgements presents some problems. Arrow's theorem as described in Laukkanen et al. (2002) states that "there is no method of aggregating individual preferences over three or more alternatives that would satisfy several conditions for fairness and always produce a logical result". Moreover, aggregation may lead to compromise that is uncomfortable and unstable. Aggregation also has the drawback of giving to the analyst the responsibility of aggregating individual preferences in order to integrate them in the analytical procedure.

Aggregation is, however the most convenient method in many situations and it might be useful for individuals or homogeneous groups to explore potential compromise between their own internal conflicts (Laukkanen et al., 2002; Belton and Stewart, 2002). Laukkanen et al. (2002), however, also argued that negotiations might be susceptible to manipulation.

Table 5 lists a sample of the aggregating methods that have been applied in group decision-making, and a brief description

Table 5
Representative methods for aggregation of individual judgements on MCDM approaches

Method	References	Description
Voting models	Laukkanen et al. (2002) and Martin et al. (1996)	Each DM form his/her own judgements for each alternative. The final judgement will be formed based on combinations of these judgements, made by use of voting systems or multi-criteria approval
Aggregation of partial utility/value functions	Belton and Stewart (2002)	After preferences have been expressed in terms of these lowest level criteria, the aggregation step can be applied either across all the criteria in a single operation or may be applied hierarchically by aggregating at each level of the value tree across those criteria which share the same parent criterion at the next highest level in the tree
Paretian analysis	Cohon (1978)	The problem is formulated as a weighted sum of the participants' utilities. The weights are varied over a range of values politically feasible. Values can be selected by examining the results and using knowledge on the political situation. The method is computationally sensitive to the number of DM
Game theory	Cohon (1978)	Interaction among DM is explicitly considered. The utility gained by a DM depends on the actions of all participants in the decision-making process. Each player is faced with an "efficiency problem" (the identification of all Pareto-optimal non-inferior alternatives) and a "bargaining problem" (the selection of one of the Pareto-optimal alternatives). These are two levels of optimisation. But game theory assumes the first way by assuming a finite set of pregenerated alternatives
Vote-trading models	Cohon (1978) and Easley et al. (2000)	They are used in the analysis of the bargaining model. Computation of vote-trading probabilities for the participants in a group decision problem in which majority rules prevails. There is the key concept of logrolling—trading votes in one issue to secure favourable votes on another. It estimates the "choice probability", then used to compute a probability for each alternative of it being chosen by the decision unit
Interactive approaches	Kim and Ahm (1999)	Individual optimisation results can be used to form a group consensus and consider strict or weak dominance values as input for aggregation procedure. This method suggests a procedure that takes account of individual DM's preference strength. The aggregated net strength of an alternative can be defined as the difference between aggregated strength of an alternative over the others and the others over the alternative considered. The alternatives can be ranked by comparing the net strength between alternatives
AHP	Malczewski et al. (1997) and Herath (2004)	Three methods employed for aggregating group member's opinions: (1) geometric mean of individual evaluations is used as element in pairwise comparison matrices and then priorities are computed; (2) in weighted average mean method, priorities are computed and then combined using a weighted arithmetic mean
AHP and fuzzy set theory	Bantayan and Bishop (1998)	Three methods employed: (1) the optimistic: takes the maximum membership from all the evaluation matrices relative to the alternative in question and the calculation is a union operation; (2) the pessimistic: attempts to minimize risk by taking the smallest membership value and the calculation is done by intersection operation; (3) mixed: a reference value, usually the midpoint value in the preference scale is determined. If the all DM agree on the acceptability of an alternative based on an objective, a pessimistic aggregate is used; otherwise an optimistic aggregate is used. In case of disagreement a compromise value is used
Folded normal AHP	Easley et al. (2000)	Assumes that the ratio judgements are probabilistic rather than deterministic, thus relaxing the requirement of consistency in group judgements. The DM, when making their judgements, draws from a distribution (generally assumed to be normal) of random variables for each stimulus, such as an attribute judged on a particular criterion. This use of a distribution function allows to explicitly take into account the variance that is likely to exist in individual and group judgements
Public value forums	McDaniels and Roessler (1998)	The group does not negotiate, but rather provides a forum for individuals to make more informed value judgements about tradeoffs. The method uses the steps of decision analysis to create a well-structured decision problem, in which individuals are asked to provide judgements about appropriate tradeoffs among competing objectives. Answers can be analysed through descriptive statistics. They are compared and reconciled

of the assumptions underlying the methodological approach taken. A review of the more general methodological approaches to synthesize individual judgements can be found in Hwang and Lin (1987) and Belton and Pictet (1997).

5. New paradigms of participatory modelling in natural resource management

Complex problems in natural resources management, involving multiple objectives, multiple decision makers and uncertainty, have been challenging practitioners, planners and

MCDA researchers to find more creative and innovative methodological approaches. Moreover, lately, there have been critical discussions about MCDA methods in particular, and traditional modelling approaches in general. These critical discussions point to the limitations of MCDA and the need for new and more flexible modelling paradigms. In this section, soft systems and knowledge-based system approaches are introduced as having potential to overcome some of the limitations of traditional MCDA methods. The critique are not meant to de-value MCDA; rather, they point to new ways of thinking about MCDA, particularly about participatory

modelling as it is applied to forest and natural resource management planning.

5.1. *The limitations of traditional MCDA approaches*

Some of the less obvious limitations of the traditional MCDM methods when dealing with the complexity of natural resources management were summarized by [Rosenhead \(1989\)](#) as follows: (1) ‘comprehensive rationality’, which unrealistically presumes or aspires to substitute analytical results and computations for judgement; (2) the creative generation of alternatives is de-emphasised in favour of presumably objective feasible and optimal alternatives; (3) misunderstanding and misrepresenting the reasons and motivations for public involvement; (4) a lack of value framework beyond the typical ‘utilitarian precepts’.

The limitations and weaknesses of traditional models are magnified when one considers a planning and decision environment that is entirely participatory. In fact, it is doubtful whether these rigid and highly algorithmic MCDA models can be adopted in an environment where citizens or local communities demand active involvement at various stages in the planning and management of resources that are of interest or value to them, and from which they can derive significant benefits or services.

In view of the above limitations, a more flexible, robust, and broad approach to MCDA application to natural resources management is needed, one that is able to deal with ill-defined problems, with objectives that might be neither clearly stated or accepted by all constituents, with unknown problem components, and with unpredictable cause-and-effect relationships. A transparent and participatory definition of the planning and decision problems would also be desirable.

5.2. *Soft systems approaches and alternative paradigms*

In recognition of the limitations of the traditional MCDM methods, a number of authors (e.g. [Rosenhead, 1989](#); [Checkland, 1981](#)) proposed an alternative paradigm, perhaps best described as ‘soft systems’ methods to address what these authors described as wicked, messy, ill-structured or difficult to define problems. According to [Rosenhead \(1989\)](#), these alternative paradigms are characterised by attributes such as: (1) search for alternative solutions, not necessarily optimal, but which are acceptable on separate dimensions without requiring explicit trade-offs; (2) reduced data demands through greater integration of hard and soft data including social judgements; (3) simplicity and transparency; (4) treatment of people as active subjects; (5) facilitation of bottom-up planning; (6) acceptance of uncertainty guided by attempts to keep options open as various subtleties of the problem are gradually revealed. An excellent review of these ‘soft methods’, or sometimes referred to as soft-operations research (OR) methods, can be found in [Belton and Stewart \(2002\)](#).

In general, soft systems approaches give less emphasis on generating solutions; instead, they give primacy to defining the most relevant factors, perspectives and issues that have to be

taken into account, and in designing strategies upon which the problem can be better understood and the decision process better guided. They are also more adequate for addressing complex problems dominated by issues relevant to, and influenced by, human concerns and their purposeful schemes ([Mendoza and Prabhu, 2002](#)). By doing so, they recognize the intrinsically complex nature of social systems and consequently attempt to avoid prematurely imposing notions of objectivity, rationality, mechanistic and predictable causality among relevant components of the problem.

Two characteristic features that are central to the soft systems approach are facilitation and structuring. Facilitation aims to provide an environment where participants or stakeholders are properly guided and discussions or debate are appropriately channelled. Structuring, on the other hand pertains to the process with which the management problem is organized in a manner that stakeholders or participants can understand, and hence, ultimately participate in the planning and decision-making processes.

Current participatory approaches seem to exhibit only the facilitation feature. Participatory action research ([Selener, 1997](#)) or rural participatory appraisal ([Chambers and Guijt, 1995](#)) are examples of these approaches now widely applied, especially in the developing world. Despite the wide popularity of these traditional participatory approaches, it has received some criticism mainly because of their apparent lack of rigor, and their limited analytical and evaluative capabilities ([Cooke and Kothari, 2001](#)). Soft-OR spans both of these processes. While facilitating a decision process that is transparent and participatory, Soft-OR methods carry the analysis further by adding more formalized representation of the problem particularly the development of structured models that provide a focus and language for discussion ([Belton and Stewart, 2002](#)). [Rosenhead \(1989\)](#) calls this alternative paradigm “problem structuring” approach. Exploring values and options in an open environment and the bottom-up approach to problem solving are some of the strengths of the problem structuring methods ([Mendoza and Prabhu, 2002](#)).

[Hjortso \(2004\)](#) provides a demonstration of a Soft-OR method for problem structuring called strategic option development and analysis (SODA) in enhancing public participation of a tactical forest management planning process. By providing a way of identifying and structuring subjective concerns and multiple conflicting objectives, SODA facilitates the understanding and agreement within the group. The author adapted the eight activities suggested by [Eden \(1989\)](#) and performed a series of interviews, workshops and analysis. The results obtained pointed to the excellent potential of SODA in enhancing stakeholders’ commitment to the final strategic forest plan.

One of the methods used in SODA is cognitive mapping, another Soft-OR method proposed by [Eden \(1988\)](#) as a network of nodes, arrows and links that represent concepts, ideas and their relationships. The result is a qualitative and comprehensive definition of the problem in its multiple facets. [Mendoza and Prabhu \(2003\)](#) have applied cognitive mapping in a qualitative approach to assessing indicators of sustainable

forest resources management. The method was used to assess the impact of the indicators by examining their interrelationships and linkages in order to look at their overall cumulative dynamic effects.

In the context of a group decision, cognitive mapping can also be seen as a structured way of group members transmitting concepts and their understanding of the structure of the problem as it was demonstrated in Tikkanen et al. (in press) in a planning exercise involving 23 forest owners. An extensive review of cognitive mapping applied to ecological modelling and environmental management is provided by Öziesmi and Öziesmi (2004). The same authors also demonstrate a fuzzy adaptation of cognitive mapping to model the views of different stakeholders on the conflict over the creation of a national park.

An alternative approach to cognitive mapping is qualitative systems dynamics (Wolstenholme, 1999), another Soft-OR approach that provides more explicit relationships between the arrows and the nodes in terms of causality, changes and impacts. Purnomo et al. (2004) have demonstrated its application in collaborative planning of community-managed resources. The study started with traditional participatory methods to fully discuss and explore different views and perspectives from the participants. This was followed by collaborative modelling, which used a combination of causality trees and causal loop diagrams to organize, in a systematic and qualitative way, the information collected previously, and to represent the interactions and causal relationships between management components. The direct participation and involvement of the stakeholders in the modelling process enabled them to contribute with their collective knowledge, expertise, and experience.

One of the strengths of Soft-OR methods applied to natural resources management is the capability they offer in structuring, and providing a better understanding of, complex problems under poor data situations. In this case, capturing and representing local knowledge is sometimes the best possible way to obtain information, and to structure a decision problem (e.g. Thomson, 2000; Mendoza and Prabhu, 2002; Sicat et al., 2005; Purnomo et al., 2004). As Thomson (2000) claims, forest management is mainly based on analysis of ‘hard’ information; hence, research is still needed to find good methods of representing traditional, local or ecological knowledge in order to make them available for modelling and planning. This need led to the development of approaches that formally analyse qualitative decision problems such as: artificial neural networks (e.g. Blackard and Dean, 1999; Moisen and Frescino, 2002; Liu et al., 2003), knowledge bases (e.g. Reynolds et al., 1996, 2000), and expert systems (e.g. Store and Kangas, 2001; Iliadis et al., 2002). Two applications in particular of these new approaches, developed as decision support systems, are the Ecosystem Management Decision Support System (EMDS) developed by Reynolds (1999) and CORMAS (Common-pool Resources and Multi-Agent Systems) developed by Bousquet et al. (1998).

As Reynolds (1999) indicated, EMDS “integrates the logic formalism of knowledge-based reasoning as implemented in the NetWeaver (Rules of Thumb, North East, PA) knowledge-

base system, into a geographic information systems”. Behind the development of EMDS there is also the acknowledgement that qualitative information became more relevant and needed with the increasingly broader complexity of ecological and natural resources problems. Consequently, EMDS makes use of fuzzy logic to represent and integrate imprecise information (Reynolds et al., 2000). Some examples of the application of EMDS to natural resources management are provided by Reynolds et al. (2000) in the assessment of a watershed condition, by Reynolds et al. (2003) in the evaluation of forest ecosystem sustainability, and by Bourgeron et al. (2000) in conducting large-scale conservation evaluation and conservation area selection.

CORMAS adopts a multi-agent systems application specifically designed for renewable resource management. Multi-agent systems evolved from knowledge-based systems, which makes it possible to represent “knowledge and reasoning of several heterogeneous agents that need to be accommodated in addressing planning problems in a collective way” (Bousquet and Le Page, 2004). A review of its applications to ecosystem management is reported by Bousquet and Le Page (2004). An integrated use of CORMAS, Geographic Information Systems (GIS), and participatory modelling was developed for the Senegal River Valley and was reported by Aquino et al. (2002) as a successful decision aid and local empowerment tool for dealing with resource management issues such as sustainable land-use management. CORMAS has also been the platform used by Purnomo et al. (2005) to develop and analyse a multi-agent simulation model of a community-managed forest.

5.3. Integrated approach to participatory modelling

The overview presented in the previous sections build the case for, and serves as a strong justification for proposing a call to a new way of thinking about MCDM applied to strategic natural resources management planning. The key word for this new approach is integration, in a parallel way, and consistent with the integrated approach proposed by Belton and Stewart (2002). The linking of a qualitative approach to problem structuring that emphasises the social aspects of the forest, with a structured approach that retains some of the analytical capabilities of the “hard systems approach”, is one of the key aspects of such an integrated approach. One advantage of an integrated approach is its ability to embrace the strengths of each method. The qualitative soft systems method allows a more participatory decision-making process with active involvement and commitment from the stakeholders. On the other hand, the quantitative and structured approach to the decision-making process is more systematic and the analyses more objective.

The difference between this integrated approach and, one in relation to traditional group MCDM methods, is that decision makers not only provide input to the model, but they also contribute to the modelling process by being involved in identifying model components, dynamics or processes between and among model components, and their relationships

(Purnomo et al., 2004; Mendoza and Prabhu, 2005). Hence, the modelling process is transparent, participatory, and accessible to decision-makers.

A dynamic integration can also be achieved using a tighter coupling of MCDA with participatory modelling. Mendoza and Prabhu (2002) exemplified the integration of MCDM methods (used to aggregate cumulative impacts of “contributing factors” in a community-forest system) with a qualitative soft system dynamic model. For example, a computer assisted model called Co-View (Collaborative Vision Exploration Workbench) developed by the Center for International Forestry Research was used to develop a qualitative systems dynamic approach to modelling.

6. Concluding remarks: future directions for MCDA in natural resource management

From the overview and critical reviews of MCDA described in the previous sections, along with the descriptions and discussions about other alternative paradigms, it is clear that MCDA offers a suitable planning and decision-making framework for natural resources management. Because it is inherently robust, it can also provide a convenient platform that lends itself well in bridging the gap between the soft qualitative planning paradigm and the more structured and analytical quantitative paradigm. Approaches that integrate these two paradigms offer some promise in terms of more adequately accommodating the inherent complexity of natural resources management, embracing ecological, biophysical, and social components, and capturing the multitude of concerns, issues, and objectives of stakeholders. Initial efforts attempting such integration indicated a very promising potential for this approach.

Belton and Stewart (2002) also suggested that the way forward for MCDA is to achieve a stronger integration of both theory and practise. They proposed a ‘hybridizing’ of methodologies that will create opportunities for ‘synergistic’ accumulation of insights from the different methods. They noted that an integrating framework must identify common elements among the methodologies and highlight the strengths of each method. They suggested further that principles identified by one MCDA school of thought should inform the implementation of methodologies employed by other schools, without these schools having to abandon their own principles. Such integration may lead to what they call, Meta-MCDA. This integration of methods is also a potential direction for future research as argued by Kangas et al. (2001a).

Mingers (2000) also offered a compelling argument for, and a strong justification to, combine soft and hard systems methods. In advancing the idea of mixing methodologies, he proposed a multi-methodology framework (Mingers and Brocklesby, 1997) that allows for mixing, linking, combining, or integrating different methodologies and paradigms. Rosenhead and Mingers (2001) stated that the “essence of multi-methodology is to utilize more than one methodology or part of thereof, possibly from different paradigms, within a single intervention”. Consequently, Rosenhead and Mingers (2001)

identified three broad types of multi-methodology frameworks as follows: *methodology combination*: uses two or more methodologies within an intervention; *methodology enhancement*: uses one main methodology but enhancing it by importing methods elsewhere; *single paradigm methodology*: combining parts of several methodologies all from the same paradigm; *multi-paradigm multi-methodology*: uses methods from different paradigms.

In terms of practise, MCDA must adopt a more participatory posture at all levels of the modelling process. Stakeholders or decision makers must be able to participate and contribute actively to modelling—from identification of model elements, formulation of relationships, and all other model components, including the actual decision-making process. This calls for a more transparent, simple, and easily accessible participatory modelling paradigm and process.

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References

- Agrell, P.J., Stam, A., Fischer, G.W., 2004. Interactive multi-objective agro-ecological land use planning: the Bungoma region in Kenya. *Eur. J. Oper. Res.* 158, 194–217.
- Alho, J.M., Kangas, J., Kolehmainen, O., 1996. Uncertainty in expert predictions of the ecological consequences of forest plans. *Appl. Stat.* 45 (1), 1–14.
- Ananda, J., Herath, G., 2003a. Incorporating stakeholder values into regional forest planning: a value function approach. *Ecol. Econ.* 45, 75–90.
- Ananda, J., Herath, G., 2003b. The use of analytic hierarchy process to incorporate stakeholder preferences into regional forest planning. *Forest Policy Econ.* 5, 13–26.
- Andreoli, M., Tellarini, V., 2000. Farm sustainability evaluation: methodology and practice. *Agric. Ecosyst. Environ.* 77, 43–52.
- Antoine, J., Fischer, G., Makowski, M., 1997. Multiple criteria land use analysis. *Appl. Math. Comput.* 83, 195–215.
- Aquino, P., Le Page, C., Bousquet, F., Bah, A., 2002. A novel mediating participatory modelling: the “self-design” process to accompany collective decision making. *Int. J. Agric. Resour. Gover. Ecol.* 2 (1), 59–74.
- Bantayan, N.C., Bishop, I., 1998. Linking objective and subjective modelling for landuse decision making. *Landscape Urban Plan.* 43, 35–48.
- Bare, B.B., Mendoza, G., 1988. Multiple objective forestland management planning: an illustration. *Eur. J. Oper. Res.* 34, 44–55.
- Blackard, J., Dean, D., 1999. Comparative accuracies of artificial neural networks and discriminant analysis in predicting forest cover types from cartographic variables. *Comput. Electron. Agric.* 24, 131–151.
- Beinat, E., Nijkamp, P. (Eds.), 1998. *Environment and Management*, vol. 9. Kluwer Academic Publishers, Boston.
- Bell, S., 2001. Landscape pattern, perception and visualisation in the visual management of forests. *Landscape Urban Plan.* 54, 201–211.
- Bella, A., Duckstein, L., Szidarovszky, F., 1996. A multi-criterion analysis of the water allocation conflict in the Upper Rio Grande Basin. *Appl. Math. Comput.* 77, 245–365.

- Belton, V., Pictet, J., 1997. A framework for group decision using a MCDA model: sharing, aggregating, or comparing individual information? *J. Decis. Syst.* 6, 283–303.
- Belton, S., Stewart, T.S., 2002. *Multiple Criteria Decision Analysis. An Integrated Approach*. Kluwer Academic Publishers, Massachusetts.
- Berbel, J., Zamora, R., 1995. An Application of MOP and GP to Wildlife Management (Deer).
- Bourgeron, P., Humphries, H.C., Reynolds, K.M., 2000. Conducting large-scale conservation evaluation and conservation area selection using a knowledge-based system. In: *Proceedings of the Fourth International Conference on Integrating G.I.S. Environmental Modelling*, Banff, Alberta, September 2–8.
- Bousquet, F., Bakam, I., Proton, H., Le Page, C., 1998. Cormas: common-pool resources and multi-agent systems. In: *Lecture Note in Artificial Intelligence*, no. 1416, Springer-Verlag, Berlin, pp. 826–838.
- Bousquet, F., Le Page, C., 2004. Multi-agent simulations and ecosystem management: a review. *Ecol. Model.* 176, 313–332.
- Buchy, M., Hoverman, S., 2000. Understanding public participation in forest planning: a review. *Forest Policy Econ.* 1, 15–25.
- Chambers, R., Guijt, I., 1995. PRA five years later—where are we now? *Forest Trees People* 26/27, 4–14.
- Chang, N.-B., Wen, C.G., Wu, S.L., 1995. Optimal management of environmental and land resources in a reservoir watershed by multi-objective programming. *J. Environ. Manage.* 44, 145–161.
- Checkland, P.B., 1981. *Systems Thinking, Systems Practice*. John Wiley and Sons, Chichester.
- Cohon, J.L., 1978. *Multi-Objective Programming and Planning*. Dover Publications, Inc., New York.
- Colfer, C.J.P., Brocklesby, M.A., Diaw, C., et al., 1999. The BAG (Basis Assessment Guide for Human Well-Being). C&I Toolbox Series no. 5. CIFOR, Bogor, Indonesia.
- Cooke, B., Kothari, U. (Eds.), 2001. *Participation: The New Tyranny?* Zed Books, London, 207 pp.
- Coughlan, B.A.K., Armour, C.L. (Eds.), 1992. *Group Decision-Making Techniques for Natural Resource Management Applications*. U.S. Department of the Interior. Fish and Wildlife Service, Washington.
- d'Angelo, A., Eskandari, A., Szidarovsky, F., 1998. Social choice procedures in water-resource management. *J. Environ. Manage.* 52, 203–210.
- Diaz-Balteiro, L., Romero, C., 2004. Sustainability of forest management plans: a discrete goal programming approach. *J. Environ. Manage.* 71, 351–359.
- Duckstein, L., Gershon, M., McAniff, R., 1982. Model selection in multi-objective decision making for river basin planning. *Adv. Water Resour.* 5, 178–184.
- Easley, R.F., Valacich, J.S., Venkataraman, M.A., 2000. Capturing group preferences in a multi-criteria decision. *Eur. J. Oper. Res.* 125, 73–83.
- Eden, C., 1988. Cognitive mapping. *Eur. J. Oper. Res.* 36, 1–13.
- Eden, C., 1989. Using cognitive mapping for strategic options development and analysis (SODA). In: Rosenhead, J. (Ed.), *Rational Analysis of a Problematic World*. John Wiley and Sons, New York, pp. 21–42.
- El-Swaify, S.A., Yakowitz, D.S. (Eds.), 1998. *Multiple objective decision making for land, water and environmental management*. Proceedings of the First International Conference on Multiple Objective Decision Support Systems (MODSS) for Land, Water and Environmental Management: Concepts, Approaches and Applications. Lewis Publishers, Florida.
- Eskandari, A., Ffolliott, P., Szidarovsky, F., 1995. Uncertainty and method choice in discrete multi-objective programming problems. *Appl. Math. Comput.* 69, 335–351.
- Gong, P., 1992. Multi-objective dynamic programming for forest resource management. *Forest Ecol. Manage.* 48, 43–54.
- Grimble, R., Chan, M.K., 1995. Stakeholder analysis for natural resource management in developing countries: some practical guidelines for making management more participatory and effective. *Nat. Resour. Forum* 19, 113–124.
- Grimble, R., Wellard, K., 1997. Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. *Agric. Syst.* 55 (2), 173–193.
- Hajkowicz, S.A., McDonald, G.T., Smith, P.N., 2000. An evaluation of multiple objective decision support techniques in natural resource management. *J. Environ. Plan. Manage.* 43 (4), 505–518.
- Hallefjord, A., Jörnsten, K., 1986. A long range forestry planning problem with multiple objectives. *Eur. J. Oper. Res.* 26, 123–133.
- Harrison, S.R., Quershi, M.E., 2000. Choice of stakeholder groups and members in multi-criteria decision models. *Nat. Resour. Forum* 24, 11–19.
- Hayashi, K., 2000. Multi-criteria analysis for agricultural resource management: a critical survey and future perspectives. *Eur. J. Oper. Res.* 122, 486–500.
- Herath, G., 2004. Incorporating community objectives in improved wetland management: the use of the Analytic Hierarchy Process. *J. Environ. Manage.* 70, 263–273.
- Hjortso, C.N., 2004. Enhancing public participation in natural resource management using Soft OR—an application of strategic option development and analysis in tactical forest planning. *Eur. J. Oper. Res.* 152, 667–683.
- Hobbs, B.F., Chankong, V., Hamadeh, W., Stakhiv, E.Z., 1992. Does choice of multi-criteria method matter? An experiment in water resources planning. *Water Resour. Res.* 28 (7), 1767–1779.
- Hwang, C.L., Masud, A.S., Paidy, S.R., Yoon, K., 1979. Multiple objective decision making, methods and applications: a state-of-the-art survey. In: *Lecture Notes in Economics and Mathematical Systems* 164, Springer-Verlag, Berlin.
- Hwang, C.L., Yoon, K., 1981. *Multiple-Attribute Decision Making: Methods and Applications*. Springer-Verlag, Berlin.
- Hwang, C.L., Lin, M.J., 1987. Group decision making under multiple criteria. Methods and applications. In: Beckman, M., Krelle, W. (Eds.), *Lecture Notes in Economics and Mathematical Systems*. Springer-Verlag, Berlin.
- Iliadis, L.S., Papastavrou, A.K., Lefakis, P.D., 2002. A heuristic expert system for forest fire guidance in Greece. *J. Environ. Manage.* 65, 327–336.
- International Labour Office, 2000. Public participation in forestry in Europe and North America. Report of the FAO/ECE/ILO Joint Committee Team of Specialists on Participation in Forestry. International Labour Office, Geneva.
- Janssen, R., 1991. *Multi-Objective Decision Support for Environmental Management*. Kluwer Academic Publishers, Boston.
- Kangas, J., 1992. Multiple-use planning of forest resources by using the analytic hierarchy process. *Scand. J. Forest Res.* 7, 259–268.
- Kangas, J., Pukkala, T., 1992. A decision theoretic approach applied to goal programming of forest management. *Silva Fenn.* 26 (3), 169–176.
- Kangas, J., Kuusipalo, J., 1993. Integrating biodiversity into forest management planning and decision-making. *Forest Ecol. Manage.* 61, 1–15.
- Kangas, J., 1994. An approach to public participation in strategic forest management planning. *Forest Ecol. Manage.* 70, 75–88.
- Kangas, J., Store, R., Leskinen, P., Mehtätalo, L., 2000. Improving the quality of landscape ecological forest planning by utilising advanced decision-support tools. *Forest Ecol. Manage.* 132, 157–171.
- Kangas, J., Kangas, A., Leskinen, P., Pykäläinen, J., 2001a. MCDM methods in strategic planning of forestry on state-owned lands in Finland: applications and experiences. *J. Multi-Criteria Decis. Anal.* 10, 257–271.
- Kangas, A., Kangas, J., Pykäläinen, J., 2001b. Outranking methods as tools in strategic natural resources planning. *Silva Fenn.* 35 (2), 215–227.
- Kangas, J., Kangas, A., 2002. Multiple criteria decision support methods in forest management. An overview and comparative analysis. In: Pukkala, T. (Ed.), *Multi-Objective Forest Management*. Kluwer Academic Publishers, The Netherlands, pp. 37–70.
- Kangas, J., Kangas, A., 2003. Multi-criteria approval and SMAA-O in natural resources decision analysis with both ordinal and cardinal criteria. *J. Multi-Criteria Decis. Anal.* 12, 3–15.
- Kangas, J., Kurttila, M., Kajanus, M., Kangas, A., 2003a. Evaluating the management strategies of a forestland estate—the S-O-S approach. *J. Environ. Manage.* 69, 349–358.
- Kangas, J., Hokkanen, J., Kangas, A.S., Lahdelma, R., Salminen, P., 2003b. Acceptability analysis to forest ecosystem management with both cardinal and ordinal criteria. *Forest Sci.* 49 (6), 928–937.
- Kangas, A.S., Kangas, J., 2004. Probability, possibility and evidence: approaches to considerer risk and uncertainty in forestry decision analysis. *Forest Policy Econ.* 5, 169–188.
- Keeney, R.L., 1992. *Value-Focused Thinking: A Path to Creative Decision Making*. Harvard University Press, Cambridge.
- Kim, S.H., Ahm, B.S., 1999. Interactive group decision making procedure under incomplete information. *Eur. J. Oper. Res.* 116, 498–507.

- Korhonen, P., Moskowitz, H., Wallenius, J., 1992. Multiple criteria decision support. A review. *Eur. J. Oper. Res.* 63, 361–375.
- Lahdelma, R., Salminen, P., Hokkanen, J., 2000. Using multi-criteria methods in environmental planning and management. *Environ. Manage.* 26 (6), 595–605.
- Laukkanen, S., Kangas, A., Kangas, J., 2002. Applying voting theory in natural resource management: a case of multiple-criteria group decision support. *J. Environ. Manage.* 64, 127–137.
- Laukkanen, S., Palander, T., Kangas, J., 2004. Applying voting theory in participatory decision support for sustainable timber harvesting. *Can. J. Forest Res.* 34, 1511–1524.
- Laukkanen, S., Palander, T., Kangas, J., Kangas, A., 2005. Evaluation of the multicriteria approval method for timber-harvesting group decision support. *Silva Fenn.* 39 (2), 249–264.
- Liu, C., Zhang, L., Davis, C., Solomon, D., Brann, T., Caldwell, L., 2003. Comparison of neural networks and statistical methods in classification of ecological habitats using FIA data. *Forest Sci.* 49, 619–631.
- Malczewski, J., Moreno-Sanches, R., Bojórquez-Tapia, L.A., Ongay-Delhuemeau, E., 1997. Multi-criteria group decision making model for environmental conflict analysis in the Cape Region, Mexico. *J. Environ. Plan. Manage.* 40 (3), 349–374.
- Malczewski, J., 1999. *GIS and Multi-Criteria Decision Analysis*. John Wiley & Sons, Inc., New York.
- Martin, W.E., Shields, D.J., Tolwinski, B., Kent, B., 1996. An application of social choice theory to USDA forest service decision making. *J. Policy Model.* 18 (6), 603–621.
- Martin, W.E., Bender, H.W., Shields, D.J., 2000. Stakeholder objectives for public lands: rankings of forest management alternatives. *J. Environ. Manage.* 58, 21–32.
- McDaniels, T.L., Roessler, C., 1998. Multi-attribute elicitation of wilderness preservation benefits: a constructive approach. *Ecol. Econ.* 27, 299–312.
- McDaniels, T.L., Thomas, K., 1999. Eliciting preferences for land use alternatives: a structured value referendum with approval voting. *J. Policy Anal. Manage.* 18 (2), 264–280.
- Memsas, D.P., 2003. Multi-objective programming methods in the reserve selection problem. *Eur. J. Oper. Res.* 150, 640–652.
- Mendoza, G.A., Campbell, G.E., Rolfe, G.L., 1986. Multiple objective programming: an approach to planning and evaluation of agroforestry systems. Part 1. Model description and development. *Agric. Syst.* 22, 243–253.
- Mendoza, G.A., 1987a. A mathematical model for generating land-use allocation alternatives for agroforestry systems. *Agroforest. Syst.* 5, 443–453.
- Mendoza, G.A., 1987b. Goal programming formulations and extensions: an overview and analysis. *Can. J. Forest Res.* 17 (7), 575–581.
- Mendoza, G.A., Campbell, G.E., Rolfe, G.L., 1987a. Multiple objective programming: an approach to planning and evaluation of agroforestry systems. Part 2. An illustrative example and analysis. *Agric. Syst.* 23, 1–18.
- Mendoza, G.A., Bare, B.B., Campbell, G.E., 1987b. Multi-objective programming for generating alternatives: a multiple-use planning example. *Forest Sci.* 33 (2), 458–468.
- Mendoza, G.A., 1988. A multi-objective programming framework for integrating timber and wildlife management. *Environ. Manage.* 12 (2), 163–171.
- Mendoza, G.A., Sprouse, W., 1989. Forest planning and decision making under fuzzy environments: an overview and illustration. *Forest Sci.* 35 (2), 481–502.
- Mendoza, G.A., Bare, B.B., Zhou, Z., 1993. A fuzzy multiple objective linear programming approach to forest planning under uncertainty. *Agric. Syst.* 41, 257–274.
- Mendoza, G.A., 1995. Analytical support in forest planning: a call for pluralistic soft systems-based approaches. Working Paper GAM, 1995. Dep. Natural Resour. Environ. Sci., University of Illinois, Champaign.
- Mendoza, G.A., Prabhu, R., 2000. Development of a methodology for selecting criteria and indicators of sustainable forest management: a case study on participatory assessment. *Environ. Manage.* 26 (6), 659–673.
- Mendoza, G.A., Prabhu, R., 2002. Enhancing participatory planning of community-managed forest using problem structuring models and approaches: experiences from a case study. Working Paper GAM – 2003 – 1. Dep. Natural Resour. Environ. Sci., University of Illinois, Champaign.
- Mendoza, G.A., Prabhu, R., 2003. Qualitative multi-criteria approaches to assessing indicators of sustainable forest resource management. *Forest Ecol. Manage.* 174, 329–343.
- Mendoza, G.A., Prabhu, R., 2005. Combining participatory modelling and multi-criteria analysis for community-based forest management. *Forest Ecol. Manage.* 207, 145–156.
- Mingers, J., Brocklesby, J., 1997. Multimethodology: towards a framework for mixing methodologies. *Int. J. Manage. Sci.* 25 (5), 489–509.
- Mingers, J., 2000. Variety is the spice of life: combining soft and hard OR/MS methods. *Intel. Trans. Oper. Res.* 7, 673–691.
- Moisen, G.G., Frescino, T.S., 2002. Comparing four modelling techniques for predicting forest characteristics. *Ecol. Model.* 157, 209–225.
- Nhantumbo, I., Dent, J.B., Kowero, G., 2001. Goal programming: application in the management of the miombo woodland in Mozambique. *Eur. J. Oper. Res.* 133, 310–322.
- Oliveira, F., Volpi, N.P., Sanquetta, C.R., 2003. Goal programming in a planning problem. *Appl. Math. Comput.* 140, 165–178.
- Özdesmi, U., Özdesmi, S.L., 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecol. Model.* 176, 43–64.
- Pasanen, K., Kurttila, M., Pykäiäinen, J., 2005. MESTA—non-industrial private forest owners' decision-support environment for the evaluation of alternative forest plans over the internet. *Int. J. Inform. Technol. Decis. Making* 4 (4), 601–620.
- Pesonen, M., Kurttila, M., Kangas, J., Kajanus, M., Heinonen, P., 2001. Assessing the priorities using A'WOT among resource management strategies at the Finnish Forest and Park Service. *Forest Sci.* 47 (4), 534–541.
- Phua, M.-H., Minowa, M., 2005. A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. *Landscape Urban Planning* 71, 207–222.
- Prato, T., 2000. Multiple attribute evaluation of landscape management. *J. Environ. Manage.* 60, 325–337.
- Pukkala, T., Miina, J., 1997. A method for stochastic multi-objective optimisation of stand management. *Forest Ecol. Manage.* 98, 189–203.
- Pukkala, T., 1998. Multiple risks in multi-objective forest planning: integration and importance. *Forest Ecol. Manage.* 111, 265–284.
- Pukkala, T. (Ed.), 2002. *Multi-Objective Forest Planning*. Kluwer Academic Publishers, London.
- Purnomo, H., Mendoza, G.A., Prabhu, R., 2004. Model for collaborative planning of community-managed resources based on qualitative soft systems approach. *J. Trop. Forest Sci.* 16 (1), 106–131.
- Purnomo, H., Mendoza, G.A., Prabhu, R., Yasmi, Y., 2005. Developing multi-stakeholder forest management scenarios: a multi-agent systems simulation approach applied in Indonesia. *Forest Policy Econ.* 7 (4), 475–491.
- Ravnborg, H.M., Westermann, O., 2002. Understanding interdependencies: stakeholder identification and negotiation for collective natural resource management. *Agric. Syst.* 73, 41–56.
- Reynolds, K., Cunningham, C., Bednar, L., Saunders, M., Foster, M., Olson, R., Schmoldt, D., Latham, D., Miller, B., Steffenson, J., 1996. A knowledge-based information management system for watershed analysis in the Pacific Northwest U.S. *AI Appl.* 10, 9–22.
- Reynolds, K.M., 1999. NetWeaver for EMDS version 1.0 user guide: a knowledge base development system. Gen. Tech. Rep. PNW-GTR-471. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.
- Reynolds, K.M., Jensen, M., Andreasen, J., Goodman, I., 2000. Knowledge-based assessment of watershed condition. *Comput. Electron. Agric.* 27, 315–333.
- Reynolds, K., Peets, S., 2001. Integrated assessment and priorities for protection and restoration of watersheds. In: *Proceedings of the IUFRO 4.11 Conference on Forest Biometry, Modelling and Information Science*, Greenwich, June 26–29, 2001, pp. 1–14.
- Reynolds, K.M., Johnson, K.N., Gordon, S.N., 2003. The science/policy interface in logic-based evaluation of forest ecosystem sustainability. *Forest Policy Econ.* 5, 433–446.
- Rogers, M., Bruen, M., 1998. Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE. *Eur. J. Oper. Res.* 107, 542–551.
- Romero, C., Rehman, T., 1987. Natural resources management and the use of multiple-criteria decision making techniques: a review. *Eur. Rev. Agric. Econ.* 14 (1), 6–89.

- Romero, C., 1990. *Handbook of Critical Issues in Goal Programming*. Pergamon Press, Oxford.
- Rosenhead, J., 1989. *Rational Analysis of a Problematic World*. John Wiley and Sons, New York.
- Rosenhead, J., Mingers, J. (Eds.), 2001. *Rational Analysis for a Problematic World Revisited*. John Wiley and Sons, Ltd., 366 pp.
- Saaty, T.L., 2001. Fundamentals of the analytic hierarchy process. In: Schmoldt, D.L., Kangas, J., Mendoza, G.A., Pesonen, M. (Eds.), *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making*. Kluwer Academic Publishers, The Netherlands, pp. 15–35.
- Selener, D., 1997. Participatory action research and social change. In: *The Cornell Participatory Action Research Network*, Cornell University Press, New York.
- Shields, D.J., Tolwinski, B., Kent, B.M., 1999. Models for conflict resolution in ecosystem management. *Socio-Econ. Plan. Sci.* 33, 61–84.
- Schmoldt, D.L., Kangas, J., Mendoza, G.A., Pesonen, M. (Eds.), 2001. *The Analytic Hierarchy Process in Natural Resources and Environmental Decision Making*. Kluwer Academic Publishers, The Netherlands.
- Sicat, R.S., Carranza, E.J., Nidumolu, U.B., 2005. Fuzzy modelling of farmer's knowledge for land suitability classification. *Agric. Syst.* 83 (1), 49–75.
- Siitonen, P., Tanskanen, A., Lehtinen, A., 2003. Selecting forest reserves with a multi-objective spatial algorithm. *Environ. Sci. Policy* 6, 301–309.
- Snyder, S., ReVelle, C., Haight, R., 2004. One and two-objective approaches to an area-constrained habitat reserve site selection problem. *Biol. Conserv.* 119, 565–574.
- Steiguer, J.E., Liberti, L., Schuler, A., Hansen, B., 2003. Multi-criteria decision models for forestry and natural resources management: an annotated bibliography. General Technical Report NE-307. U.S.D.A. Forest Service, Northeastern Research Station, Newton Square, PA.
- Steuer, R.E., Schuler, A.T., 1978. An interactive multiple-objective linear programming approach to a problem in forest management. *Oper. Res.* 26 (2), 254–269.
- Stewart, T.J., Janssen, R., Van Herwijnen, M., 2004. A genetic algorithm approach to multi-objective land use planning. *Comput. Oper. Res.* 31, 2293–2313.
- Store, R., Kangas, J., 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS based habitat suitability modelling. *Landscape Urban Plan.* 55, 79–93.
- Tarp, P., Helles, F., 1995. Multi-criteria decision making in forest management planning—an overview. *J. Forest Econ.* 1 (3), 273–306.
- Thomson, A.J., 2000. Elicitation and representation of traditional ecological knowledge, for use in forest management. *Comput. Electron. Agric.* 27, 155–165.
- Tikkanen, J., Isokääntä, T., Pykäläinen, J., Leskinen, P., in press. Applying cognitive mapping approach to explore the objective-structure of forest owners in a Northern Finnish case area. *Forest Policy Econ.*
- UNCED, 1992. The non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests. Report on the United Nations Conference on Environment and Devpt. Rio de Janeiro, June 3–14, 1992.
- Vacik, H., Lexer, M.J., 2001. Application of a spatial decision support system in managing the protection forests of Vienna for sustained yield of water resources. *Forest Ecol. Manage.* 143, 65–76.
- Wolstenholme, E.F., 1999. Qualitative vs. quantitative modelling: the evolving balance. *J. Oper. Res. Soc.* 50, 422–428.
- Wondolleck, J.A., Manring, N.J., Crawfoot, J.E., 1996. Teetering at the top of the ladder: the experience of citizen group participation in alternative dispute resolution processes. *Sociol. Perspect.* 39 (2), 249–262.
- Yoon, K.P., Hwang, C.-L., 1995. *Multiple Attribute Decision Making: An Introduction*. Sage Publications, Thousand Oaks, CA.
- Zahedi, F., 1986. The analytic hierarchy process—a survey of the method and its applications. *Interfaces* 16, 96–108.
- Zeleny, M., 1982. *Multiple Criteria Decision Making*. McGraw-Hill, New York.
- Zeleny, M., 1984. *MCDM: Past Decade and Future Trends: A Source Book of Multiple Criteria Decision Making*. JAI Press, Greenwich.

Recovery Strategy for the Northern Goshawk *laingi* subspecies (*Accipiter gentilis laingi*) in Canada

Northern Goshawk *laingi* subspecies



2018



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For copies of the recovery strategy, or for additional information on species at risk, including COSEWIC Status Reports, residence descriptions, action plans, and other related recovery documents, please visit the [Species at Risk \(SAR\) Public Registry](http://sararegistry.gc.ca/default.asp?lang=En&n=24F7211B-1)¹.

Cover illustration: Ross Vennesland (adult female Northern Goshawk, *Accipiter gentilis laingi*, on Vancouver Island, British Columbia).

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¹ <http://sararegistry.gc.ca/default.asp?lang=En&n=24F7211B-1>

RECOVERY STRATEGY FOR THE NORTHERN GOSHAWK *LAINGI* SUBSPECIES (*Accipiter gentilis laingi*) IN CANADA

2018

Under the Accord for the Protection of Species at Risk (1996), the federal, provincial, and territorial government signatories agreed to work together on legislation, programs, and policies to protect wildlife species at risk throughout Canada.

In the spirit of cooperation of the Accord, the Government of British Columbia has given permission to the Government of Canada to adopt the *Recovery Strategy for the Northern Goshawk, laingi subspecies (Accipiter gentilis laingi) in British Columbia* (Part 2) under Section 44 of the *Species at Risk Act* (SARA). Parks Canada Agency has included a federal addition (Part 1) which completes the SARA requirements for this recovery strategy.

The federal recovery strategy for the Northern Goshawk, *laingi* subspecies in Canada consists of two parts:

Part 1 – Federal Addition to the *Recovery Strategy for the Northern Goshawk laingi subspecies (Accipiter gentilis laingi) in British Columbia*, prepared by the Parks Canada Agency.

Part 2 – *Recovery Strategy for the Northern Goshawk, laingi subspecies (Accipiter gentilis laingi) in British Columbia*, prepared by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team for the British Columbia Ministry of Environment

Table of Contents

Part 1 – Federal Addition to the <i>Recovery Strategy for the Northern Goshawk laingi</i> subspecies (<i>Accipiter gentilis laingi</i>) in British Columbia, prepared by the Parks Canada Agency.....	1
Preface.....	2
Acknowledgments	3
Additions and Modifications to the Adopted Document	4
1. COSEWIC Species Assessment Information	4
2. Population and Distribution Objectives	5
3. Broad Strategies and General Approaches Recommended to Meet the Population and Distribution Objectives	8
4. Critical Habitat	9
4.1. Identification of Critical Habitat.....	9
4.1.1. Location of Critical Habitat	12
4.1.2. Biophysical Attributes of Suitable Habitat.....	12
4.1.3. Amount of Suitable Habitat Required for Critical Habitat	16
4.1.4. Maps of Critical Habitat.....	21
4.2. Schedule of Studies to Identify Critical Habitat.....	21
4.3. Activities Likely to Result in the Destruction of Critical Habitat.....	23
4.4. Summary of Current Provincial Measures to Manage Activities within Northern Goshawk Habitat.....	25
5. Measuring Progress	25
6. Socio-Economic Considerations.....	26
7. Action Plan	26
8. Effects on the Environment and Other Species	27
9. References	28
Appendix A: Northern Goshawk Habitat Suitability Index Models	35
Appendix B: Amount and Location of Critical Habitat.....	38
 Part 2 – <i>Recovery Strategy for the Northern Goshawk, laingi subspecies (Accipiter gentilis laingi) in British Columbia</i> , prepared by the Northern Goshawk <i>Accipiter gentilis laingi</i> Recovery Team for the British Columbia Ministry of Environment	50

Part 1 – Federal Addition to the *Recovery Strategy for the Northern Goshawk laingi* subspecies (*Accipiter gentilis laingi*) in British Columbia, prepared by the Parks Canada Agency

Preface

The federal, provincial, and territorial government signatories under the [Accord for the Protection of Species at Risk \(1996\)](#)² agreed to establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada. Under the *Species at Risk Act* (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of recovery strategies for listed Extirpated, Endangered, and Threatened species and are required to report on progress within five years after the publication of the final document on the SAR Public Registry.

The Minister of Environment and Climate Change and Minister responsible for the Parks Canada Agency is the competent minister under SARA for the recovery of the Northern Goshawk, *laingi* subspecies and has prepared the federal component of this recovery strategy (Part 1), as per Section 37 of SARA. To the extent possible, it has been prepared in cooperation with the Province of British Columbia, First Nations, environmental non-governmental organizations, academic experts, and other stakeholders including representatives of industrial and small-scale forestry operators, as per Section 39(1) of SARA. SARA Section 44 allows the Minister to adopt all or part of an existing plan for the species if it meets the requirements under SARA for content (Sub-sections 41(1) or (2)). The Province of British Columbia provided the attached *Recovery Strategy for the Northern Goshawk, laingi subspecies (Accipiter gentilis laingi) in British Columbia* (Part 2) as science advice to the jurisdictions responsible for managing the species in British Columbia. It was prepared in cooperation with Environment and Climate Change Canada.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy and will not be achieved by Environment and Climate Change Canada, the Parks Canada Agency, or any other jurisdiction alone. All Canadians are invited to join in supporting and implementing this strategy for the benefit of the Northern Goshawk *laingi* subspecies and Canadian society as a whole.

This recovery strategy will be followed by one or more action plans that will provide information on recovery measures to be taken by Environment and Climate Change Canada and the Parks Canada Agency and other jurisdictions and/or organizations involved in the conservation of the species. Implementation of this strategy is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations.

The recovery strategy sets the strategic direction to arrest or reverse the decline of the species, including identification of critical habitat to the extent possible. It provides all Canadians with information to help take action on species conservation. When critical habitat is identified, either in a recovery strategy or an action plan, SARA requires that critical habitat then be protected.

² <http://registrelep-sararegistry.gc.ca/default.asp?lang=En&n=6B319869-1%20>

In the case of critical habitat identified for terrestrial species, SARA requires that critical habitat identified in a federally protected area³ be described in the *Canada Gazette* within 90 days after the recovery strategy or action plan that identified the critical habitat is included in the public registry. A prohibition against destruction of critical habitat under ss. 58(1) will apply 90 days after the description of the critical habitat is published in the *Canada Gazette*.

For critical habitat located on other federal lands, the competent minister must either make a statement on existing legal protection or make an order so that the prohibition against destruction of critical habitat applies.

For any part of critical habitat located on non-federal lands, if the competent minister forms the opinion that any portion of critical habitat is not protected by provisions in or measures under SARA or other Acts of Parliament, or the laws of the province or territory, SARA requires that the Minister recommend that the Governor in Council make an order to prohibit destruction of critical habitat. The discretion to protect critical habitat on non-federal lands that is not otherwise protected rests with the Governor in Council.

Acknowledgments

This federal addition to the Province of British Columbia's Recovery Strategy for the Northern Goshawk, *laingi* subspecies (*A. gentilis laingi*) in British Columbia was produced by the Parks Canada Agency, with input from the Northern Goshawk *Accipiter gentilis laingi* Recovery Team and Habitat Recovery Implementation Group (RIG). In particular, Parks Canada would like to acknowledge the crucial science support provided for the critical habitat identification by the following members of the recovery team and/or Habitat RIG: John Deal, David Donald, Frank Doyle, Todd Mahon, Erica McClaren, Louise Waterhouse and Berry Wijdeven. Input was also received from Vanessa Craig, Manon Dubé, Wendy Dunford, Megan Harrison, Paul Johanson, Dave Lindsay, Ian Parnell, Kella Sadler, Warren Warttig and Steven Wilson. Several forestry organizations provided technical input during consultations, including but not limited to British Columbia Timber Sales, Coast Forest Products Association, Interfor, Island Timberlands, TimberWest and Western Forest Products. Critical habitat mapping for breeding areas was conducted by Todd Mahon, Todd Manning, Peter Berst and Paul Chytyck. Appendix A was compiled by Todd Mahon. This federal recovery strategy would not be possible without the many years of effort that the Northern Goshawk *Accipiter gentilis laingi* Recovery Team and Habitat Recovery Implementation Group spent developing the provincial recovery strategy (NGRT 2008; Part 2) that forms the backbone to this federal addition.

³ These federally protected areas are: a national park of Canada named and described in Schedule 1 to the *Canada National Parks Act*, The Rouge National Park established by the *Rouge National Urban Park Act*, a marine protected area under the *Oceans Act*, a migratory bird sanctuary under the *Migratory Bird Convention Act, 1994* or a national wildlife area under the *Canada Wildlife Act* see ss. 58(2) of SARA.

Additions and Modifications to the Adopted Document

The following sections have been included to address specific requirements of the federal *Species at Risk Act* (SARA) that are not addressed in the *Recovery Strategy for the Northern Goshawk, laingi subspecies (Accipiter gentilis laingi) in British Columbia* (NGRT 2008; Part 2 of this document, referred to henceforth as “the provincial recovery strategy”) and/or to provide updated or additional information.

Under SARA, there are specific requirements and processes set out regarding the protection of critical habitat. Therefore, statements in the provincial recovery strategy referring to protection of survival/recovery habitat may not directly correspond to federal requirements. Recovery measures dealing with the protection of habitat are adopted; however, whether these measures will result in protection of critical habitat under SARA will be assessed following publication of this final federal recovery strategy.

1. COSEWIC* Species Assessment Information

This updated COSEWIC species assessment (COSEWIC 2013) replaces the COSEWIC species assessment information provided in the provincial recovery strategy.

Assessment Summary – May 2013

Common Name

Northern Goshawk

Scientific Name

Accipiter gentilis laingi

Status:

Threatened

Reason for Designation

Over half of the global range of this subspecies occurs in coastal British Columbia, where it favours mature coniferous forest. This non-migratory bird needs a relatively large home range that contains a good food supply. Despite some recent habitat protection efforts, continuing habitat loss is predicted, in part because of anticipated short rotation times in forest harvest. On Haida Gwaii, populations are very low and face an added risk from declines of prey species due to forest understory losses associated with high levels of browsing from an introduced population of deer.

Occurrence

British Columbia

Status History

Designated Special Concern in April 1995. Status re-examined and designated Threatened in November 2000 and May 2013.

*COSEWIC (Committee on the Status of Endangered Wildlife in Canada)

2. Population and Distribution Objectives

This section replaces the recovery goal section in the provincial recovery strategy.

The provincial recovery strategy defined four conservation regions for the *laingi* subspecies in coastal British Columbia (NGRT 2008): 1) Haida Gwaii, 2) North Coast, 3) Vancouver Island and 4) South Coast. This federal recovery strategy adopts these regions, but as in COSEWIC (2013) and MoFLNRORD (2018) also includes what NGRT (2008) defined as a transition zone between ranges of the *laingi* and *atricapilus* subspecies. This part of the coast is included as a precautionary measure until better information is available on range boundaries because much of this zone has similar forest structure, forest composition and prey assemblages as other parts of the *laingi* range (MoFLNRORD 2018).

In the provincial recovery strategy, the recovery goal was: “*to ensure viable populations ... persist in each conservation region in coastal British Columbia*”. The term ‘viable’ was not defined in the provincial recovery strategy either quantitatively or qualitatively, and as such this goal was difficult to translate into an amount of critical habitat required to support the survival or recovery of the species.

This federal recovery strategy includes quantitative population and distribution objectives for both survival over the short term (defined as 3 generations, or 15 years, COSEWIC 2013), and recovery over the long term (defined as 15 to 65 years). The short term objectives provide a benchmark towards meeting the long term objective. A step wise approach is being used because of the complexity of managing habitat on the coast of British Columbia, due largely to the limited availability of suitable habitat for both breeding and foraging, the slow rate of recruitment of suitable habitat (forests begin to become suitable at a minimum of 65 years; Mahon *et al.* 2015) and a general lack of robust science linked directly to population indices (see Section 4).

In general, the Northern Goshawk will be considered recovered when the main threats (habitat loss and over-browsing by introduced species on Haida Gwaii that has resulted in reduced prey availability; NGRT 2008) have been addressed, when the Canadian portion of the population has achieved a degree of resilience, when suitable habitat for multiple sub-populations is available and protected (representation), and when sufficient suitable habitat is available to allow for perpetuation of the Northern Goshawk population without relying on direct and ongoing intervention (Government of Canada 2016).

Note that Northern Goshawk was assessed as Threatened in part because of a threat of habitat loss that is in part due to relatively short rotation times currently used by the forest harvest industry (COSEWIC 2013). This threat can be addressed by extending rotation times or alternatively by protecting an adequate amount of habitat to meet the population and distribution objectives.

Resilience refers to the ability of a population to recover from a perturbation. Resilience is influenced by population size, level of genetic diversity, as well as

characteristics of the species and its habitat. In order for a species to be resilient the abundance would have to be large enough to have a high probability of persistence. Probability of persistence can be estimated using a population viability analysis (PVA).

There are only a few published reports that have attempted to estimate the viability of Northern Goshawk populations but many were not able to reach a conclusion because of a lack of data or because of high variability in the limited data that were available (Maguire and Call 1993, Broberg 1997, Ingraldi 2001). However, Steventon (2012a, 2012b) successfully conducted a PVA for the *laingi* subspecies on the coast of British Columbia with input and peer review from members of the Province of British Columbia's Northern Goshawk *Accipiter gentilis laingi* Recovery Team. The PVA had a significant degree of uncertainty due to sparse data on population metrics, and did not consider gene flow to the range of the *laingi* subspecies outside of Canada (primarily Alaska), but nonetheless provides a quantitative information source for setting recovery targets.

Steventon (2012a, 2012b) suggested that 346 home ranges⁴ would be required in British Columbia for a 90% probability of persistence over 100 years. As one of five primary criteria for assessing the risk of extinction or extirpation of species, COSEWIC assesses species as Threatened if they have a 90% probability of persistence over 100 years or less. This threshold (90% over 100 years) essentially reflects the threshold for what would be required to remove the *laingi* subspecies from its assessment as Threatened. This would satisfy the resilience component for the *survival* of the listed species.

To ensure survival of Northern Goshawk over the short term, a target of 346 home ranges throughout the Canadian range has been chosen for this Threatened species. Distributing this target among the four conservation regions in Canada based on their relative proportions of the Canadian population (as per COSEWIC 2013), sufficient habitat would need to be maintained for 15 home ranges on Haida Gwaii (4.5%), 111 home ranges on the North Coast (31.9%), 125 home ranges on Vancouver Island (36%), and 95 home ranges on the South Coast (27.5%). However, given the isolation of Haida Gwaii and limited exchange of genes with the rest of the Canadian population (Talbot *et al.* 2011, Sonsthagen *et al.* 2012), 15 home ranges is likely too small to prevent inbreeding. Conservation biology theory suggests a minimum of 50 breeding individuals is required to reduce the risk of extinction due to the negative effects of inbreeding depression on demography (Franklin 1980, Soulé 1980, Jamieson and Allendorf 2012). Given an estimated home range occupancy rate of 43% (COSEWIC 2013) and an estimated 1/3 of the population being mature adults not occupying a home range (COSEWIC 2013), 38 home ranges would be required to support 50 breeding adults on Haida Gwaii.

⁴ Northern Goshawks are distributed in adult pairs that occupy a home range (sometimes referred to as a territory; COSEWIC 2013). The number of home ranges (rather than the number of birds) is used for the purposes of setting population and distribution objectives.

Therefore, the population and distribution objectives for the Northern Goshawk *laingi* subspecies in Canada over the short term (defined as three generations, or 15 years, COSEWIC 2013) are to:

1. Maintain sufficient suitable habitat to support at least 369 Northern Goshawk *laingi* subspecies home ranges in Canada, and
2. Ensure that sufficient suitable habitat is available amongst the four conservation regions of the Northern Goshawk *laingi* subspecies in Canada to support home ranges as follows: Haida Gwaii – 38 home ranges, North Coast – 111 home ranges, Vancouver Island – 125 home ranges, and South Coast – 95 home ranges.

Recovery of a species is considered by Government of Canada (2016) as a range of options over a continuum from the minimum feasible recovery threshold (defined as a level that exceeds survival, approximates historical representation, improves condition over what was first assessed and does not rely on continued intervention) to the maximum feasible recovery threshold (defined as full recovery; typically the historical condition minus habitat that has been irreversibly changed).

Population sizes were not quantified in early species assessments (e.g., COSEWIC 2000), but in COSEWIC (2013) it was estimated that there was sufficient habitat in the Canadian range to support 723 home ranges (circa 2005 to 2012; Mahon *et al.* 2015). The minimum feasible recovery threshold is therefore considered to be 724 home ranges distributed across all four conservation regions as per the historic capability of each region. This level will exceed that required for short term survival and should provide for resilience, representation and perpetuation without intervention.

Steventon (2012a, 2012b) used data from Smith and Sutherland (2008) and, by simulating what current forests may have looked like historically, estimated that prior to industrial scale forestry there was sufficient habitat for between 740 and 1219 home ranges in Canada (median = 980). As per COSEWIC (2013), approximately 3% of the Northern Goshawk *laingi* subspecies Canadian range has been permanently lost to urban and agricultural development since European settlement. The maximum feasible recovery threshold is therefore estimated to be 951 home ranges.

The population and distribution objective for recovery of the Northern Goshawk in Canada over the long term (15 to 65 years) is thus to:

Maintain sufficient habitat to support between 724 and 951 Northern Goshawk *laingi* subspecies home ranges in Canada, distributed across all four conservation regions as per the historic habitat capability of each region.

Achievement of the long term objective within 65 years was considered appropriate because newly harvested stands on the southern coast of British Columbia (where forest harvesting has been most extensive) will begin to become suitable for Northern Goshawk nesting at about 65 years (Mahon *et al.* 2015). The historic habitat capability

of each region was estimated by Smith and Sutherland (2008), but requires revision based on updated conservation region boundaries (Table 1).

3. Broad Strategies and General Approaches Recommended to Meet the Population and Distribution Objectives

The majority of the approaches recommended to meet the population and distribution objectives are contained in the recovery planning table of the provincial recovery strategy (Part 2; Table 3. Broad strategies that will be used to address threats and to achieve recovery of habitat and populations for *A. gentilis laingi*). Additional recommended approaches are included here (see Table 1) to meet the federal population and distribution objectives and to lay the groundwork for future recovery planning.

Table 1. Additional Recommended Approaches.

Approach / Strategy	Description of Management and Research Approaches	Outcome / Deliverables	Priority
Discover or manage habitat for additional home ranges to meet population and distribution objectives.	- Option 1 – Discover additional home ranges through the use of surveys for home ranges. - Option 2 – Manage suitable habitat at a landscape level to ensure long term viability of a sufficient number of home ranges.	A sufficient number of home ranges are discovered or managed to meet population and distribution objectives.	Urgent
Develop approaches to mitigate human induced mortality.	- Human induced mortality is a significant issue in at least one region (where landowners are protecting chickens; B. Wijdeven, pers. comm.). - Assist landowners to implement non-lethal measures, where appropriate.	Reduced human induced mortality.	Urgent
Genetic analysis.	Conduct additional genetic analyses to confirm the range of the <i>laingi</i> subspecies.	Revised range boundaries for <i>laingi</i> subspecies.	Necessary

Approach / Strategy	Description of Management and Research Approaches	Outcome / Deliverables	Priority
Refine population and distribution objectives.	- The population and distribution objectives require adjustment due to the inclusion of the transition zone in the federal recovery strategy. - The historic capability of each region needs to be determined for the long term objective.	Revised population and distribution objectives that account for inclusion of the transition zone and clarify how many home ranges are required in each region.	Necessary
Refine Steventon (2012 a,b) Population Viability Analysis (PVA).	Additional work is required to refine the PVA and reduce its level of uncertainty, as well as include the effects of gene flow to areas outside of Canada.	Refinements to both short and long term population and distribution objectives.	Beneficial

4. Critical Habitat

This section replaces the Critical Habitat section in the provincial recovery strategy.

4.1 Identification of Critical Habitat

The *Species at Risk Act* defines critical habitat as “... the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species’ critical habitat in a recovery strategy or action plan for the species.”

Critical habitat in this recovery strategy is identified for 91 Northern Goshawk breeding home ranges across the four conservation regions: 18 in the Haida Gwaii Conservation Region, 19 in the North Coast Conservation Region, 33 in the Vancouver Island Conservation Region and 21 in the South Coast Conservation Region (Appendix B).

Critical habitat is identified based on Northern Goshawk data available to the Government of Canada from the British Columbia Conservation Data Centre (CDC). Although COSEWIC (2013) provided modelling estimates that suggested the current Canadian population was between 682 and 764 home ranges (mean = 723), only 110 home ranges were available from the British Columbia CDC for potential inclusion in this critical habitat identification (BC CDC 2014).

This critical habitat identification is considered to be a partial identification of critical habitat because:

- Additional surveys (or a different approach to the critical habitat identification) will be required to identify additional suitable and/or occupied habitat to meet the population and distribution objectives (Tables 1 and 3).
- Some critical habitat has not been identified due to insufficient available information. Habitat Suitability Index model output is currently not available for the transition zone (between coastal to interior habitat types; Section 2), and for some lands (mostly private forestry lands and provincial parks) on Vancouver Island (Section 4.1.2);
- Some critical habitat has not been identified due to ongoing cooperation and consultation. The Government of Canada will continue to work cooperatively with applicable organizations to complete the identification of critical habitat; and
- Critical habitat is only identified for home ranges at the scale of the breeding season because habitat requirements for the non-breeding season are not well understood (McClaren *et al.* 2015).

A schedule of studies (Table 3) has been developed to provide the information necessary to complete the identification of critical habitat that will be sufficient to meet the population and distribution objectives.

The identification of critical habitat in this recovery strategy is based on the scale of a breeding home range for the Northern Goshawk. A Northern Goshawk breeding home range (Figure 1) consists of a hierarchical arrangement of components that includes a nest or a cluster of nests that are used by a pair of Northern Goshawks over time (from one to 12 nests on the coast of British Columbia; Mahon *et al.* 2013), Post Fledging Areas (PFAs; see provincial recovery strategy in Part 2) around each nest, a breeding area that includes all PFAs, and a larger foraging area (reviewed by Squires and Kennedy 2006, NGRT 2008, Mahon *et al.* 2013, McClaren *et al.* 2015). The breeding area is the core use area of Northern Goshawks during the breeding season, and is where juveniles spend the majority of their time prior to leaving their natal home range (Kennedy *et al.* 1994, McClaren *et al.* 2005; reviewed by Squires and Reynolds 1997, Squires and Kennedy 2006, McClaren *et al.* 2015). It typically includes multiple nest sites, each having an associated PFA (Kennedy *et al.* 1994, McClaren *et al.* 2005; reviewed by Manning 2012, Mahon *et al.* 2013, McClaren *et al.* 2015). The larger foraging area makes up the majority of the breeding home range and is where the adults hunt (Iverson *et al.* 1996, Bloxton 2002; reviewed by Squires and Reynolds 1997, NGRT 2008, McClaren *et al.* 2015). Foraging areas, and consequently home ranges, vary in size, reflecting differences in the availability of prey, hunting efficiency of individuals, and food requirements (Iverson *et al.* 1996, Bloxton 2002, Mahon *et al.* 2013; reviewed by Squires and Kennedy 2006; NGRT 2008, McClaren *et al.* 2015).

Both breeding areas and foraging areas are considered critical to ensure successful breeding and survival of Northern Goshawks (reviewed by Squires and Reynolds 1997, Daust *et al.* 2010, NGRT 2008, McClaren *et al.* 2015). Therefore, this recovery strategy includes an identification of critical habitat for breeding (based on known nests) and critical habitat for foraging around known nests. These are key concepts in the critical

habitat identification because they delineate the areas within which critical habitat is identified. While breeding and foraging areas are distinct from one another, any given breeding area is overlapped by its associated and larger foraging area. This means that habitat managed for a breeding area can also contribute to habitat requirements for the associated foraging area. The biophysical attributes and amounts of critical habitat required are different for these two home range components, as described below.

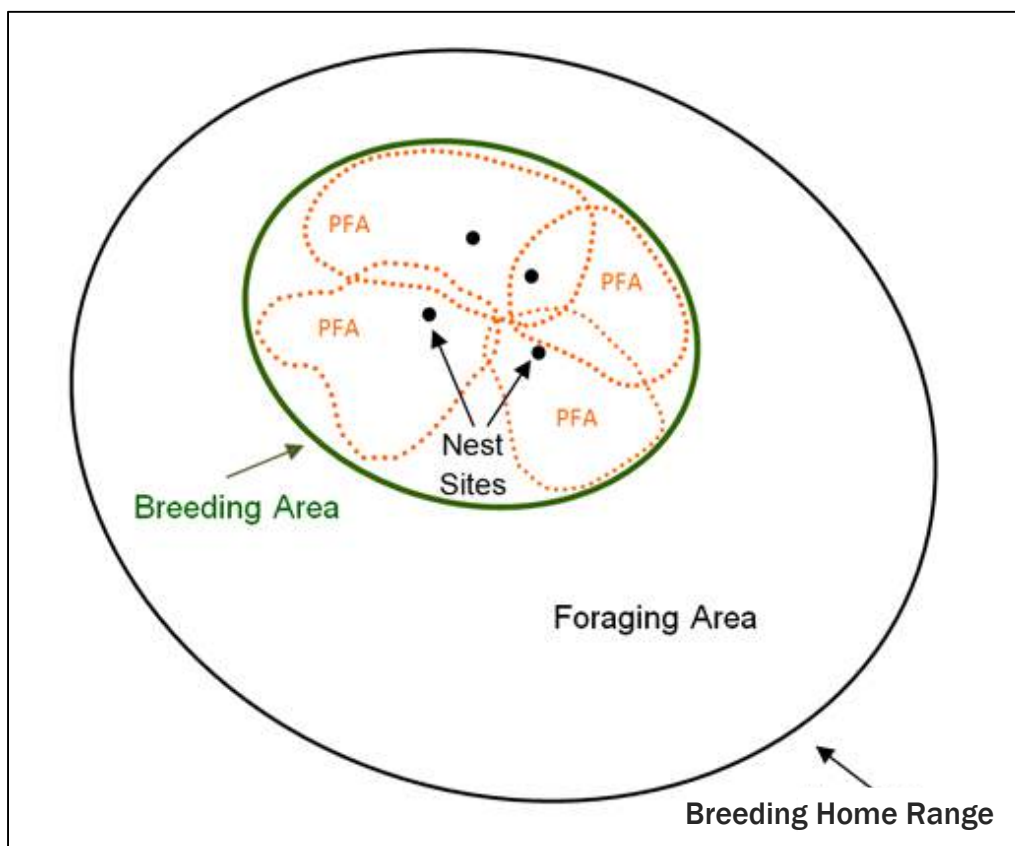


Figure 1. Conceptual illustration of the components of a Northern Goshawk breeding home range (modified from McClaren *et al.* 2015).

Critical habitat is identified in terms of its location, its biophysical attributes, and the amount of it required:

- *Location* describes where critical habitat is found geographically.
- *Biophysical attributes* describe the biological and physical characteristics of the suitable habitat.
- *Amount* describes the quantity and extent of suitable habitat required at each location and/or across the species' distribution.

This recovery strategy outlines and applies a methodology to identify the location, biophysical attributes, and amount of critical habitat required in a breeding home range. The configuration, amount and location of suitable habitat within a home range may change over time. If more suitable habitat is available than required within a given home

range, different areas of critical habitat can be identified and published in an amended recovery strategy and/or action plan. However, at any point in time, the critical habitat must meet the criteria for location, biophysical attributes and amount described herein (where suitable habitat is available).

4.1.1. Location of Critical Habitat

The location of critical habitat is based on the locations of known nests of the Northern Goshawk within coastal British Columbia for which data were available to the Government of Canada as of June 2014. Data on nest locations for 110 Northern Goshawk breeding home ranges were obtained from the British Columbia Conservation Data Centre (CDC). All records of Northern Goshawk nests were included in the identification, irrespective of age of observation or recent occupancy (BC CDC 2014). Breeding home ranges without evidence of recent occupancy were included because Northern Goshawks are difficult to detect and annual monitoring is limited over much of the species range (until recently, intensive annual monitoring only occurred on parts of Vancouver Island⁵ and Haida Gwaii⁶), because they exhibit strong site fidelity to a breeding home range (McClaren 2005, Stuart-Smith *et al.* 2012), and because they have been known to re-occupy a particular area even after many years of apparent absence (Kenward 2006, McClaren *et al.* 2015, Province of British Columbia unpubl. data). Consequently, areas where Northern Goshawks have previously been detected are likely to continue to be used by Northern Goshawks, even if they are not detected over several surveys (McClaren 2005). In addition, given the relatively small number of birds known to occur in each conservation region, inclusion of unoccupied nests and/or breeding home ranges is considered necessary, as a precautionary measure, to ensure sufficient nesting locations and breeding home ranges are available to contribute towards providing a reasonable probability of long term persistence (Steventon 2012; see Section 2 *Population and Distribution Objectives*). If through field surveys, critical habitat is confirmed to be unsuitable for Northern Goshawk nesting or foraging, critical habitat can be refined and published in an amended recovery strategy and/or action plan.

4.1.2. Biophysical Attributes of Suitable Habitat

Habitat Suitability Index (HSI) models for Northern Goshawk breeding areas and foraging areas were produced collaboratively by the Habitat Recovery Implementation Group of the Province of British Columbia's Northern Goshawk *Accipiter gentilis laingi* Recovery Team (Mahon *et al.* 2008, 2015). The Mahon *et al.* (2015) models are based on Northern Goshawk habitat usage, and use equations that describe the combination of habitat attributes that are thought to be required by Northern Goshawks. The models are used to analyze standardized British Columbia forest cover data and to score forest stands (on a scale of 0-1) according to how suitable they are predicted to be for Northern Goshawks (with 0.5 to 1 defined as suitable).

⁵ For example, Manning and Chytyk (2008).

⁶ For example, Doyle (2005).

The biophysical attributes of suitable habitat differ slightly between breeding areas and foraging areas, with breeding habitat being a subset of foraging habitat. In general, mature/old growth forests most often possess the characteristics considered suitable for Northern Goshawks. However, because the models are based on multiple variables, there is some flexibility in the attributes of forests that are rated as suitable. For example, younger forest stands might still qualify as suitable habitat if they have high ratings for all other variables and as long as minimum height and age criteria are met.

The Mahon *et al.* (2015) HSI models are the only information sources that have quantitatively defined the attributes of Northern Goshawk habitat on the coast of British Columbia. They are based on the largest data set of nest locations and Northern Goshawk telemetry data that is available for coastal British Columbia, so represent the most comprehensive descriptions of suitable habitat for breeding and foraging. The Mahon *et al.* (2015) HSI models have not been published and have not been validated (see Section 3.2 *Schedule of Studies*), but were ground tested for accuracy in each of the four conservation regions (meeting a priori accuracy targets; see Appendix A), were subjected to sensitivity analyses, and have been reviewed by a broad cross section of practitioners in British Columbia (Mahon *et al.* 2008, 2015). The models were iteratively improved as a result of these processes and as more recent data have become available (Mahon *et al.* 2015).

The models are the best tools available to quantify Northern Goshawk habitat currently available. There are no other options available for a multi-parameter quantitative description of suitable habitat. An alternative approach to the use of Mahon *et al.*'s (2015) models would be to use a single parameter, such as tree age or tree height. However, this option would not provide a precise description of suitable habitat (e.g., old trees at high elevation will not be suitable, old trees of certain species will not be suitable, tall trees in some cases will not have the required branching structure to effectively hold nests). The Mahon *et al.* (2015) models take into account the variance in suitability based on the primary factors affecting habitat use for which standard forest cover data are available for mapping. As such, the models provide the most precise description of suitable habitat, based on the largest amount of data on habitat use by Northern Goshawks.

Because the models represent a description of typical habitat use, there will be cases where the models do not fully represent a particular local situation (e.g., highly managed forest lands in a productive landscape). In situations such as these, further planning may allow the models to be tailored to specific landscapes or different scales (e.g., through a home range plan based on a management unit or conservation region, see Section 3.2 *Schedule of Studies*). In cases such as this, the critical habitat identification may be refined for the landscape being considered in an amended recovery strategy and/or action plan.

Spatial mapping output of the Mahon *et al.* (2015) HSI models has been produced using land cover data current to between 2005 and 2012 (Mahon *et al.* 2008, 2015) and is used in this federal recovery strategy to spatially map critical habitat. Although the HSI models met the ground testing accuracy requirements set by the provincial recovery

team (Mahon *et al.* 2015), there remains considerable error associated with the model output (related primarily to the accuracy of underlying forest cover data). Nevertheless, there is no alternative for spatially mapping of critical habitat at this time. Field verification of model outputs can be used to improve the accuracy of mapped critical habitat (Section 3.2 *Schedule of Studies*). In addition, as of 2017 the mapped model output was not available for large areas of Vancouver island (mostly private lands owned by the forest industry and provincial parks), and for the eastern margin of the Canadian range of the *laingi* subspecies, as considered in this federal recovery strategy (Section 2).

Critical habitat is only identified within critical habitat boundaries where the biophysical attributes of critical habitat are present.

See Section 3.2 *Schedule of Studies* for activities to refine the identification of critical habitat, including production of HSI model outputs for the transition zone (from coastal to interior habitat types), provincial parks, protected areas and private lands on Vancouver Island, and field verifications of current model outputs.

Critical habitat for breeding: biophysical attributes

Biophysical attributes of suitable habitat for breeding typically include mature/old forest with large trees suitable for holding large stick nests, a relatively closed canopy (> 50%), an open understory and abundant under-canopy flyways (Iverson *et al.* 1996, Patla 1997, Daw and DeStephano 2001, Finn *et al.* 2002, McGrath *et al.* 2003, Desimone and DeStefano 2005, Doyle 2005, McClaren 2005, Boal *et al.* 2006, Harrower *et al.* 2010, Stuart-Smith *et al.* 2012, Mahon *et al.* 2013; reviewed by Squires and Reynolds 1997, MWLAP 2004, Squires and Kennedy 2006, USFWS 2007, NGRT 2008, Mahon *et al.* 2015).

Using the following equation from the HSI model for breeding habitat (Mahon *et al.* 2015), suitable habitat for breeding must have a HSI rating of 0.5 or more, where:

$$HSI_n = \text{mean}(\text{Age}_r, \text{Height}_r) * \text{Edge}_r * \text{ITG}_r * \text{Elev}_r * \text{Slope}_r * \text{BECvar}_r,$$

and where n = nesting and r = rating, from 0-1, based on estimates of how that particular variable affects habitat suitability for Northern Goshawk breeding (see Mahon *et al.* 2015).

The mean tree stand age (Age_r) and height (Height_r) are included in the model because Northern Goshawks generally prefer older and taller trees. Estimates of breeding habitat suitability increase linearly from 0 below 40 years and 14 m height up to 1 at 90 years of age and 32 m height. Northern Goshawks also tend to avoid anthropogenic and natural edges (Edge_r), so breeding sites farther away from edges are more suitable and receive a higher rating. Inventory Type Group variable (ITG_r) relates certain structural requirements such as canopy to particular forest types. Structural attributes important to Northern Goshawk breeding appear to be most common in hemlock, fir and spruce dominated stands. As such, these forest types typically receive a rating of 1, whereas other forest types have lower ratings. The elevation of an area (Elev_r) is included in the

model because data suggest that Northern Goshawks prefer lower elevation sites. Lower elevation areas (400 m on Haida Gwaii, 600 m on the North Coast and 800 m in the southern regions receive a rating of 1; with downgrades to a low of 0.5 at 1,300 m. Slope (Slope_r) is included because the vast majority of known nests occur on slopes <60%. Areas with a slope between 0-60% receive a rating of 1; areas with slopes >60% receive a reduced rating. The final variable in the model is the BEC variant (BECvar_r), which represents the classification of the area based on the British Columbia Biogeoclimatic Ecosystem Classification System (MacKinnon *et al.* 1992). Each class was assigned a rating, based on estimated habitat suitability for breeding. For example, tundra and alpine parkland classes have the lowest ratings at 0.4. See Appendix A for more details on the variables included in the model.

In addition to the attributes described in the model, an important biophysical attribute of critical habitat for breeding is habitat that is free from loud auditory disturbances during the breeding season from courtship to fledging (15 February – 31 July) (Iverson *et al.* 1996; reviewed by Cooper and Stevens 2000). Activities that create loud noise within or adjacent to an active breeding area can cause disturbances for nesting birds and may have negative consequences for production of young and mortality of young or adults (e.g., Boal and Mannan 1994, Toyne 1997, Bijslma 1999 in Rutz *et al.* 2006, Penteriani and Faivre 2001, Doyle in Stuart-Smith *et al.* 2012; reviewed by McClaren *et al.* 2015). For information on mitigation, see Section 2.3 *Activities Likely to Result in the Destruction of Critical Habitat*.

Where HSI model output was not available, other available data were used to delineate critical habitat for breeding. This included satellite imagery, forest cover information for timber supply area lands, and mapping data on recent and proposed cutblocks (from the Government of British Columbia's Land and Resource Data Warehouse).

Critical habitat for foraging: biophysical attributes

There is strong evidence that Northern Goshawks prefer to forage in forests with typical mature/old characteristics (e.g., closed canopy, low stem density, open understory). Eight of nine telemetry studies that were conducted during the breeding season in primarily forested areas of North America found that goshawks foraged in forests with mature/old structural characteristics disproportionately more often than the availability of these forests on the landscape (Austin 1993, Bright-Smith and Mannan 1994, Beier and Drennan 1997, Bloxton 2002, Hargis *et al.* 1994, Iverson *et al.* 1996, Good 1998, Boal *et al.* 2006, Mahon 2009). Forest structure has usually been found to be more important than prey abundance to goshawk foraging, likely because forest structure is a key attribute for prey accessibility. For example, a closed canopy results in a relatively open understory and a low stem density increases sub-canopy flyways; both of which increase access to prey (reviewed by Greenwald *et al.* 2005 and McClaren *et al.* 2015). The biophysical attributes of typical foraging habitat include relatively large trees (a low stem density), open understories and closed canopies; though a variety of other habitat types (e.g., alpine areas and shorelines when used by migratory species) are also used (Bloxton 2002, Iverson *et al.* 1996, Boal *et al.* 2006; reviewed by USFWS 2007, NGRT 2008, Stuart-Smith *et al.* 2012, COSWIC 2013, Mahon *et al.* 2015).

Using the following equation from the HSI model for foraging areas (Mahon *et al.* 2015), suitable habitat for foraging must have a HSI rating of 0.5 or more, where

$$\text{HSI}_f = \text{mean}(\text{Age}_r, \text{Height}_r) * \text{ITG}_r * \text{BECvar}_r \text{ or Non-Forest rating, whichever is greater,}$$

and where f = foraging and r = rating. Non-Forest rating is any area that is not classified as a forest type under the British Columbia Biogeoclimatic Ecosystem Classification Program. See above (*Critical habitat for breeding areas: biophysical attributes*) for explanations of the relevant model variables and Appendix A for more details on the variables included in the model.

4.1.3. Amount of Suitable Habitat Required for Critical Habitat

The biophysical attributes above describe biological and physical characteristics of suitable habitat, but not all suitable habitat is necessarily critical habitat.

Critical habitat for breeding: amount of suitable habitat

The amount of suitable breeding habitat required for critical habitat around each nest is 75.5 ha. This is based on an empirical analysis of the use of habitat by fledglings using telemetry for 12 *laingi* nests in British Columbia that found 90% of the nests had a PFA size of up to 75.5 ha (McClaren *et al.* 2005, Mahon *et al.* 2013, McClaren *et al.* 2015). Use of the 90th percentile should ensure that there will be sufficient critical habitat for breeding around each nest for most situations, which is important for species at risk, especially given that breeding areas represent the core use area of a breeding home range (Kennedy *et al.* 1994, Iverson *et al.* 1996, Moser 2009, McClaren *et al.* 2015).

Critical habitat for breeding should provide a buffer for nests from hard edges⁷ such as harvested areas (McClaren 2005, Iverson *et al.* 1996, Mahon *et al.* 2013, McClaren *et al.* 2015). Several studies have found that Northern Goshawks relocated their nests in response to timber harvesting near their nest locations (Penteriani and Faivre 2001, Mahon 2009, Stuart-Smith *et al.* 2012). Although not tested compared to controls, a recent analysis of 283 nests on Vancouver Island and Haida Gwaii, Mahon *et al.* (2013) found that 90% of nests were at least 252 m from cut-blocks that were present at the time the nest was first discovered. Additionally, McClaren *et al.* (2005) and McClaren (2005) found that radio-tagged Northern Goshawk fledglings were never confirmed using open areas such as harvested areas (E. McClaren, pers. comm. 2014).

Beyond ensuring sufficient suitable breeding habitat around known nests, additional critical habitat is required in some breeding home ranges to allow for the establishment of new nests. The number of nests within 63 breeding areas of the *laingi* subspecies in coastal British Columbia ranged from one to 12 nests, with a 90th percentile of about six nests (Mahon *et al.* 2013). Therefore, using a precautionary approach, the critical habitat in each breeding area should provide sufficient suitable breeding habitat for

⁷ A hard edge is defined as an abrupt change in the forest canopy, typically where mature or old forest is adjacent to non-forested habitat or younger forest, and where the height difference between the two habitat types is at least 15 m (e.g., clearcut edge, lake shore, alpine area).

supporting PFAs for at least six nests. Given that the median distance between nests is 275 m and the 90th percentile of intra-nest distances is 840 m (Parks Canada, unpubl. data, n=294 intra-nest distances from 111 breeding home ranges), each supplementary PFA area, where necessary, should be centered at a location not less than 275 m and not more than 840 m from a known nest or other supplementary PFA locations.

Based on the above, critical habitat for breeding requires:

- 75.5 ha of suitable breeding habitat around each known nest. The critical habitat must encompass the nest tree, and the critical habitat must be located within 840 m of each nest. In addition, there must be at least 252 m of contiguous suitable breeding habitat around each nest. Any suitable habitat within 840 m of more than one nest can count towards the critical habitat necessary for each of those nests. If there is currently insufficient suitable habitat around a known nest to meet the 75.5 ha target, critical habitat will include all currently available suitable habitat within the 840m radius of the nest and the area should be managed to achieve the 75.5 ha through appropriate management actions outlined in an amended recovery strategy or action plan.
- For breeding home ranges with fewer than six known nests, additional critical habitat for breeding (75.5 ha per location, as above) will be required in order to allow for the establishment of new nests. The additional critical habitat for breeding areas should be centered at locations not less than 275 m and not more than 840 m from known nests or supplementary nest locations, so that a total of six known or supplementary nest locations are contained within the critical habitat for breeding areas for each breeding home range. Where insufficient suitable habitat exists, the area should be managed to achieve this over time through appropriate management actions outlined in an amended recovery strategy, home range plan or action plan.

Critical habitat for foraging: amount of suitable habitat required

Critical habitat for foraging, defined biophysically using the HSI model on the coast of British Columbia (Mahon *et al.* 2015), typically has mature/old forest characteristics. As outlined earlier, there is strong evidence that Northern Goshawks disproportionately select foraging habitat with mature/old forest characteristics over other habitats such as young forests and open areas. Given this result, it is not surprising that five of seven studies have shown a positive relationship between home range occupancy and the amount of forest with mature/old characteristics within home ranges (Crocker-Bedford 1990, Crocker-Bedford 1995, Ward *et al.* 1992, Patla 2005, Finn *et al.* 2002, McClaren and Pendergast 2003, Mahon 2009). In British Columbia, a recent analysis suggested that Northern Goshawks have selected home ranges for the amount of critical habitat for foraging within them on both Haida Gwaii and Vancouver Island (Vennesland 2018). Data was not available for other conservation regions.

Critical habitat for foraging has declined on the coast of British Columbia, though there is some evidence that this decline has slowed in recent years. COSEWIC (2013) documented a widespread 20% to 31% (depending on the region) decline in critical habitat for foraging since industrial scale forestry began. Czembor (2012) used recent

satellite land cover data (Spot imagery from 2004 to 2007 and Landsat imagery from 1999 to 2011) and HSI modelled habitat (Mahon *et al.* 2015), and documented a decline in suitable foraging habitat of approximately 1% per year on the South Coast and Vancouver Island. On the North Coast, critical habitat for foraging had increased slightly (<0.2%) and no data were available for Haida Gwaii. More recently, the Province of British Columbia (unpubl. data) found only a very slight (<1%) overall decline across all conservation regions from 2000 to 2015, balanced by slight increases on the North Coast and South Coast and a slightly stronger decline (2.6%) on Vancouver Island. The difference between the results of Czembor (2012) and Province of British Columbia (unpubl. data) may be due to declining rates of harvest or better accounting for recruitment that offsets declines from harvesting in the unpublished data from the Province of British Columbia.

As with breeding areas, there is limited unequivocal information about the size of the home range (or foraging area) and how much suitable foraging habitat is required within the home range (reviewed by NGRT 2008, Stuart-Smith *et al.* 2012, McClaren *et al.* 2015). For example, home ranges vary in size, in part according to ecological conditions such as weather and prey availability as well as between males and females (Kennedy *et al.* 1994, Iverson *et al.* 1996, Bloxton 2002). Both the size and quality of breeding home ranges likely vary across the four conservation regions (Doyle 2005, Doyle 2006, NGRT 2008, Deal and Mogensen 2013, Mahon *et al.* 2013, Manning and Chytyk 2018). Most studies have recommended that 40-60% of the full landscape area within home ranges be composed of suitable foraging habitat, including specifically for the coast of British Columbia (McClaren *et al.* 2015). However, these recommendations (in British Columbia and elsewhere) have typically not been based on clear empirical information (e.g., Reynolds *et al.* 1992).

To determine the amount of suitable habitat required for critical habitat for foraging within the breeding home range, two steps were followed: 1) mean breeding home range size was determined, and 2) the amount of suitable habitat required to be critical habitat within this foraging area was determined. To ensure a regionally appropriate critical habitat identification, these values were determined separately for each conservation region (and in some cases, the regions were further subdivided to reflect variation where data were available; see maps B-1 to B-6, Appendix B). The results are summarized in Table 2.

First, regional estimates of mean breeding home range size (based on the spacing of breeding home ranges on the landscape) were used to determine the size of foraging areas used by Northern Goshawks during the breeding season (McClaren *et al.* 2015, Manning and Chytyk 2018). Previous studies determined that breeding home range spacing for the *laingi* subspecies was highest on Haida Gwaii (Doyle 2006, NGRT 2008), where McClaren *et al.* (2015) estimated home range spacing at 10.4 km. McClaren *et al.* (2015) also estimated home range spacing for Vancouver Island at 6.9 km. A more recent study by Manning and Chytyk (2018) looked at home range spacing in all regions except for Haida Gwaii using updated data (Province of British Columbia, unpubl. data) and estimated home range spacing for the North Coast near Bella Coola where home ranges appear to be tightly packed (4.8 km), remaining areas of the North

Coast (6.6 km), the Coastal Dry Ecosystem Zone that encompasses a large area of Vancouver Island and smaller areas of the North Coast and South Coast regions (6.1 km), and remaining areas of Vancouver Island (6.9 km) and the South Coast (6.6 km). Spacing estimates reflect the presumed diameter of home ranges, which was used to calculate the estimated area of home ranges (Table 2). The region or sub-region of a home range was defined by where the home range centroid was located.

Sub-regional spacing estimates were considered in determining the amount of suitable habitat required in home ranges because detailed survey data in both the Bella Coola region of the North Coast and in the Coastal Dry Ecosystem Zone of the south (defined as the Coastal Douglas-fir biogeoclimatic zone and the Coastal Western Hemlock xm1 and xm2 subzone variants; MacKinnon *et al.* 1992) suggested that home ranges were more tightly spaced in these areas, likely due to different ecological conditions that increase prey abundance/availability (Manning and Chytyk 2018). Conversely, on Haida Gwaii, the negative effects of introduced deer on prey availability is presumed to have resulted in a wider spacing of home ranges as goshawks must fly further to find sufficient prey for successful breeding (Doyle 2005; reviewed by NGRT 2008).

These estimates of mean breeding home range sizes likely under-estimate the true size of home ranges because of several biases (Manning and Chytyk 2018), most prominently because estimates of home range spacing have been produced considering all known home ranges whether or not they were known to be occupied. However, the estimates of home range size likely over-estimate the annual required amount of suitable habitat because Northern Goshawks tend to use a relatively small area of their breeding home range each year (e.g., 32% as per Kennedy *et al.* 1994; see also Bloxton 2002, Moser 2009). Balancing these biases in the data, the mean of the observed breeding home range sizes should provide a reasonable and precautionary conservation target.

Second, the amount of suitable habitat required within the foraging area of each breeding home range was determined based on the amount of suitable foraging habitat (as predicted by the Mahon *et al.* 2015 foraging HSI model) that was present in breeding home ranges that had evidence of occupation in at least one year over the period 2000 to 2017 (Province of British Columbia, unpubl. data). Given the general lack of strong empirical results for the required amount of suitable habitat in a home range, this recovery strategy uses a 'no net loss' strategy to cease further habitat loss while studies are undertaken to provide better science on goshawk requirements. To this end, the amount of critical habitat for foraging required in each home range is based on the 50th percentile (median) of the proportions of suitable habitat across breeding home ranges with evidence of occupation. The median was chosen rather than the mean because these data are typically not symmetrically distributed and the median thus provides a better representation of the general tendency of the midpoint of the data. The same six conservation regions or sub-regions were used for this analysis as with the home range spacing analysis. Median values for each region or sub-region were computed as the average median proportion from 2000 to 2015 of suitable habitat in the full landscape of home ranges (Province of British Columbia, unpubl. data).

The median amount of suitable habitat in breeding home ranges with evidence of occupation was 65.5% for Haida Gwaii, 49.5% for the North Coast, 50.1% for the Bella Coola area of the North Coast, 44.6% for Vancouver Island, 47.4% for the South Coast and 50.0% for the Coastal Dry Ecosystem Zone (Province of British Columbia, unpubl. data).

The total amount of suitable habitat needed for critical habitat for foraging in breeding home ranges is summarized in Table 2. In the South Coast region for example, the target for critical habitat for foraging is 1622 ha of suitable habitat within a 6.6 km diameter circle of the nest centroid (the centroid of all known nests and supplementary nest locations) for the breeding home range.

Table 2. The maximum diameter requirement (based on breeding home range size estimates) for critical habitat for foraging, and the percentage and total amount of suitable habitat that is required for each breeding home range, for each of the six conservation regions and sub-regions considered for critical habitat for foraging.

Conservation Region or Sub-region ¹	Breeding home range diameter estimate (km)	Suitable habitat required (%) ⁴	Amount suitable habitat required for critical habitat for foraging (ha)
Haida Gwaii	10.4 ²	65.5	5,564
North Coast	6.6 ³	49.5	1,693
North Coast – Bella Coola	4.8 ³	50.1	907
Vancouver Island	6.9 ^{2,3}	44.6	1,668
South Coast	6.6 ³	47.4	1,622
Coastal Dry Ecosystem Zone	6.1 ³	50.0	1,461

¹ See maps B-1 to B-6 (Appendix B) for regional and sub-regional boundaries (Manning and Chytk 2018).

² McClaren *et al.* (2015)

³ Manning and Chytk (2018)

⁴ Median proportion of home ranges comprised of suitable foraging habitat (based on mean of estimates from 2000 to 2015; Province of British Columbia, unpubl. data).

Because foraging within any given home range occurs throughout the breeding home range, critical habitat for breeding will also contribute to the required amount of critical habitat for foraging (critical habitat for breeding always overlaps with critical habitat for foraging).

If the amount of suitable habitat available within the breeding home range radius estimate is currently less than the amount of suitable habitat required (Table 2) and critical habitat includes all currently available suitable habitat within the polygon, the regionally appropriate threshold should be achieved over time through appropriate management actions outlined in an amended recovery strategy, home range plan or action plan. Of the 91 home ranges for which critical habitat has been identified, the

amount of suitable habitat required for foraging critical habitat is currently below the estimated targets for 79 home ranges (see Table B-1 in Appendix B). The remaining 12 home ranges had an amount of suitable habitat at or above the estimated targets. In cases where the amount of suitable habitat available in a home range was above the required foraging critical habitat target in Table 2, the breeding home range radius was reduced until the amount of suitable habitat for foraging critical habitat was reached. This method was used based on the prediction that habitat utility will decline with distance from the breeding area, as per the theory of Central Place Foraging (Orians and Pearson 1979; for example, Bloxton 2002).

4.1.4. Maps of Critical Habitat

The areas containing critical habitat for breeding and critical habitat for foraging for the Northern Goshawk are presented in Appendix B, Figures B-2 to B-6. Within the areas identified as containing critical habitat for Northern Goshawk, critical habitat is identified only where the biophysical attributes are found (Section 3.1.2). Detailed methods and decision-making processes relating to the critical habitat identification are archived in a supporting document.

Home ranges with small amounts of critical habitat may not be obvious on the maps included in this appendix, so it is recommended that those with interests on the land base acquire more detailed mapping resources (e.g., GIS spatial layers). For access to detailed mapping resources and supporting documents outlining the methods used for critical habitat in this strategy, please see the contact information listed for Northern Goshawk *laingi* subspecies on the Species at Risk Public Registry:
<http://www.registrelep-sararegistry.gc.ca/>.

4.2 Schedule of Studies to Identify Critical Habitat

A list of studies and activities recommended to achieve a complete identification of critical habitat for Northern Goshawk is provided in Table 3. Further studies and activities are required to 1) identify additional critical habitat that is required for the survival and recovery of the species, and 2) possibly refine critical habitat identification to maximize its implementation effectiveness (e.g., verify whether critical habitat identification is most effective at a breeding home range, a management unit, or a regional scale).

Table 3. Studies and activities required for a full identification of critical habitat for Northern Goshawk to meet the population and distribution objectives for the species in this federal recovery strategy.

Description of activity	Outcome/rationale	Timeline
To meet the population and distribution objectives, identify additional critical habitat in 1) currently known home ranges that have an insufficient amount of critical habitat (Table B-1, Appendix B), and 2) additional home ranges found through surveys or habitat mapped at a landscape scale (see also Table 1).	A sufficient amount of critical habitat is identified to meet the population and distribution objectives.	Ongoing
Some critical habitat has not been identified due to ongoing cooperation and consultation. The Government of Canada will continue to work cooperatively with applicable organizations to increase the amount of critical habitat identified.	- Increased amount of critical habitat identified. - Progress made towards achieving population and distribution objectives.	Ongoing, pending progress respecting consultations
Produce HSI model output for lands where currently not available (e.g., transition zone from coastal to interior habitat types, provincial parks and private lands on Vancouver Island, see Section 4.1)	To increase the number of breeding home ranges for which HSI data are available, allowing more critical habitat to be identified.	2019-2022
Conduct research to determine the required availability of breeding and foraging habitat at home range and/or landscape scale.	- Results will provide a better understanding of the breeding and foraging habitat thresholds required to sustain the overall Northern Goshawk population on the coast of British Columbia, and can be applied to re-assess the approach to identify critical habitat. - Additional empirical evidence, including occupancy and reproductive success where possible, will help to assess current thresholds and approaches to identifying foraging habitat. - Determine the extent to which areas with HSI ratings <0.5 can occur within a	2019-2024

Description of activity	Outcome/rationale	Timeline
	breeding or foraging area without having an effect on long-term occupancy.	
Continue to research critical habitat knowledge gaps (e.g., patterns of home range use in breeding and non-breeding seasons, prey abundance, availability and diversity).	- Information on winter habitat associations may influence the habitat included in critical habitat. - Knowledge of relationships between prey abundance, availability and diversity and foraging habitat characteristics will allow the refinement of specific foraging habitat targets for different habitat types. - Additional data to allow validation of HSI and other models. - Assessment of potential alternatives to current habitat models. - Assessment of the benefit of spacing and/or thinning for enhancing habitat suitability. - Assessment of and approaches to deal with introduced deer on Haida Gwaii. - Knowledge of the relationship between rotation times of harvested forest and Northern Goshawk occupancy can be used to better manage critical habitat.	2019-2024
Validation of the HSI model outputs at stand-level scale.	Improve accuracy/precision of critical habitat boundaries.	2019-2029

4.3 Activities Likely to Result in the Destruction of Critical Habitat

Understanding what constitutes destruction of critical habitat is necessary for the protection and management of critical habitat. Examples of activities likely to destroy critical habitat are provided below (Tables 4 and 5). However, destructive activities are not limited to those listed. Destruction is determined on a case by case basis.

Destruction would result if part of the critical habitat were degraded, either permanently or temporarily, such that it would not serve its function when needed by the species. Destruction may result from single or multiple activities at one point in time or from cumulative effects over time.

Destruction of Northern Goshawk critical habitat includes, but is not limited to, the alteration or removal of forest suitable for breeding or foraging. In addition, loud noises occurring between the beginning of courtship (approximately mid-February) until fledging (approximately beginning of August) can disturb Northern Goshawks and potentially reduce the quality of the habitat in which they reside. Disturbance stimuli can

cause the abandonment of nests, which can result in the mortality of eggs or young in the nest (Craig 2002, Environment Canada 2014).

Table 4. Examples of activities within or near to critical habitat for breeding and foraging that are likely to result in the destruction of critical habitat at all times of the year.

Activity categories	Examples of potential effects on habitat	Examples of potential effects on Northern Goshawk
• Forest harvesting, such as clear cutting, that removes critical habitat. • Industrial or urban/residential development that removes or alters critical habitat (e.g., oil and gas, mines, construction of buildings or other infrastructure, hydro dams, roads and other linear developments, etc.)	• Reduces quality and or quantity of critical habitat for breeding and critical habitat for foraging • Negatively affects prey populations	• Insufficient critical habitat remains to maintain a breeding pair of Northern Goshawks • Reduced availability of prey • Increased rate of predation of adults with increased edge habitats • Increased rate of breeding abandonment from human disturbance • Greater competition with edge or open habitat-adapted species

Table 5. Examples of activities likely to destroy critical habitat for breeding during the breeding season, and proposed setback distances that will make the activity unlikely to destroy critical habitat. Proposed setbacks were determined using the results of previous studies and considerations of the potential of a stimulus to cause a disturbance (i.e., potentially intense stimuli deserve more precautionous setbacks; Environment Canada 2014). Mitigations should be in effect from courtship to the end of the nestling phase (15 February – 31 July; Iverson 1996, reviewed by Cooper and Stevens 2000).

Disturbance stimuli	Buffer distance from active nest (m)
Hauling with truck ¹	100
Road construction ²	500
Tree Felling ³	500
Aircraft ⁴ - repeated overflights or any overflights of heavy lift aircraft	1,000 ⁶
Blasting ⁵	1,000

¹ McLaughlin (2002), Grubb *et al.* (2012), Deal (2013), E. McClaren pers. comm.

² Vernier and Brunnell (2002), Stuart-Smith *et al.* (2012), E. McClaren pers. comm.

³ Boal and Mannan 1994, Penteriani and Faivre 2001, McLaughlin (2002), Stuart-Smith *et al.* (2012), E. McClaren pers. comm.

⁴ Stuart-Smith *et al.* (2012), E. McClaren pers. comm.

⁵ McLaughlin (2002), Stuart-Smith *et al.* (2012), E. McClaren pers. comm.

⁶ Aircraft buffer distance applied horizontally and vertically.

It should be noted that loud disturbance stimuli such as described here may only temporarily destroy critical habitat for breeding. The effects of noise disturbance may be very short (e.g., an adult temporary leaves the nest), occur for one season (e.g., the adults abandon the nest for the season but return the next year) or longer if the nest is abandoned for one or more years. But it is likely that if the physical habitat attributes remain suitable, the site should continue to be viable once the disturbance stimuli have ceased.

4.4 Summary of Current Provincial Measures to Manage Activities within Northern Goshawk Habitat

Substantial work has already been completed or is underway to manage activities within habitat for Northern Goshawk in British Columbia. For example, 1.6 million ha of suitable breeding and foraging habitat occurs in provincial forestry reserves and parks (MoFLNRO and MoE 2013). In addition, provincial ‘fine filter’ regulations constrain forest harvesting activities on the managed land base within 28 known breeding areas using Wildlife Habitat Areas, or WHAs, under the Forest and Range Practices Act, FRPA, or Reserves under the Land Act. These WHAs and Reserves total to 4,300 ha of core breeding habitat (i.e., suitable breeding and post-fledging habitats) and over 14,000 ha of suitable foraging habitat (MoFLNRO and MoE 2013).

Specific activities in some breeding and foraging habitat on provincial Crown land are constrained within:

- Parks and protected areas (e.g., British Columbia *Park Act*);
- Ungulate Winter Ranges through the FRPA;
- Old Growth Management Areas through the British Columbia *Land Act*;
- Conservancies, Biodiversity, Mining and Tourism Areas and Strategic Level Reserve Design polygons within the Ecosystem-based Management planning area on the North and Central Coast (e.g., Horn *et al.* 2009); and
- Strategic Land Use Agreements (SLUAs) with protection under Land Use Objectives Orders under the British Columbia *Land Act* (e.g., on Haida Gwaii).

In addition to the habitats under the designations described above, timber harvesting in British Columbia is regulated through an “allowable annual cut” that is based on modelling of timber supply. Over the long term, it is projected that a steady state of forest age-classes (both structure and distribution) will be achieved so that the amount of old and mature age classes will become relatively constant over the long term (MoFLNRO and MoE 2013).

5. Measuring Progress

Performance measure for short term Population and Distribution Objective 1:

- Within 15 years of final posting of the strategy, there is sufficient suitable habitat in Canada to meet critical habitat targets for at least 369 breeding home ranges⁸.

Performance measure for short term Population and Distribution Objective 2:

- Within 15 years of final posting of the strategy, there is sufficient suitable habitat to meet critical habitat targets across all four conservation regions (suitable habitat for at least 38 breeding home ranges⁸ on Haida Gwaii, 111 on the North Coast, 125 on Vancouver Island, and 95 on the South Coast).

Performance measures for long term Population and Distribution Objective:

- Within 65 years of final posting of the strategy, there is sufficient suitable habitat in Canada to meet critical habitat targets for between 724 and 951 breeding home ranges⁸.
- Within 65 years of final posting of the strategy, sufficient suitable habitat for between 724 and 951 breeding home ranges⁸ in Canada is distributed across conservation regions as per the historic capability of each region (to be determined, see Table 1).

6. Socio-Economic Considerations

The section in the provincial recovery strategy entitled Socioeconomic Considerations is not considered part of the federal SARA recovery strategy for this species.

A socio-economic analysis is not required in a recovery strategy under Section 41(1) of SARA. A formal evaluation of the socio-economic costs and benefits of implementing the action plan(s) will be included in one or more action plan(s) as required by SARA (Section 49(e)).

7. Action Plan

This section modifies information in the provincial recovery strategy.

One or more actions plans for Northern Goshawk will be completed and posted on the Species at Risk Public Registry five years following the final posting of this federal recovery strategy.

It is expected that home range plans will be developed to outline how breeding home ranges will be managed to maintain or attain a sufficient amount of critical habitat over

⁸ Breeding home ranges are based on British Columbia Conservation Centre records and do not require recent evidence of occupancy because of the difficulty in detecting Northern Goshawks, a lack of widespread annual monitoring, and because they have been known to re-occupy a particular area even after many years of apparent absence (see details in Section 3.1.1).

time. Home range plans may be stand-alone documents or components of other planning documents, including action plans. The main purpose of a home range plan would be to outline how activities within the breeding home range will be managed over space and time to ensure a sufficient amount of critical habitat is protected from destruction. As such, each home range plan should outline the measures and steps that will be taken to manage the interaction between human disturbance, natural disturbance, and the need to maintain or establish sufficient breeding or foraging habitat to satisfy the requirements described in this recovery strategy.

8. Effects on the Environment and Other Species

A strategic environmental assessment (SEA) is conducted on all SARA recovery planning documents, in accordance with the [Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals](#)⁹. The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally sound decision-making and to evaluate whether the outcomes of a recovery planning document could affect any component of the environment or any of the [Federal Sustainable Development Strategy](#)'s¹⁰ (FSDS) goals and targets.

Recovery planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that strategies may also inadvertently lead to environmental effects beyond the intended benefits. The planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts upon non-target species or habitats. The results of the SEA are incorporated directly into the strategy itself, but are also summarized below in this statement.

This recovery strategy will clearly benefit the environment by promoting the recovery of the Northern Goshawk, *laingi* subspecies through addressing knowledge gaps associated with population size, intra- and interspecific competition, amount and distribution of critical habitat, and winter habitat / diet associations; and reduction / mitigation of threats and maintenance of sufficient habitat on the landscape (long term).

The SEA concluded that this recovery strategy would have several positive effects and not cause any important negative effects. Other wildlife with similar habitat requirements and experiencing similar threats would stand to benefit from this recovery strategy. Further project-specific environmental assessments of actions identified as a result of research conducted in this recovery strategy, may be required.

⁹ <http://www.ceaa.gc.ca/default.asp?lang=En&n=B3186435-1>

¹⁰ <http://www.ec.gc.ca/dd-sd/default.asp?lang=En&n=CD30F295-1>

9. References

- Austin, K.K. (1993). Habitat use and home range size of breeding northern goshawks in the southern Cascades. M.Sc. Thesis, Oregon State University, Corvallis, OR.
- Beier, P., and Drennan, J.E. (1997). Forest structure and prey abundance in foraging areas of Northern Goshawks. *Ecological Applications* 7(2): 564-571.
- Bloxton Jr, T.D. (2002). Prey abundance, space use, demography, and foraging habitat of Northern Goshawks in western Washington. Doctoral dissertation, University of Washington, WA.
- Boal, C.W., and Mannan, R.W. (1994). Northern Goshawk diets in ponderosa pine forests on the Kaibab Plateau. *Studies in Avian Biology* 16: 97-102.
- Boal, C.W., Andersen, D.E., Kennedy, P.L., and Roberson, A.M. (2006). Northern Goshawk ecology in the western Great Lakes region. *Studies in Avian Biology* 31: 32-40.
- BC CDC (Conservation Data Centre). (2014). Data request for Northern Goshawk *laingi* subspecies nest locations. Available from: <http://www.env.gov.bc.ca/cdc/> (accessed June 2014).
- Bright-Smith, D.J. And R.W. Mannan. (1994). Habitat use by breeding male Northern Goshawks in Northern Arizona. *Studies in Avian Biology* 16: 58-65.
- Broberg, L.E. (1997). Final population viability analysis of the Queen Charlotte Goshawk (*Accipiter gentilis laingi*) in southeastern Alaska. Environmental Studies Program, University of Montana. Unpublished report.
- Cooper, J.M., and V. Stevens. (2000). A review of the ecology, management and conservation of the Northern Goshawk in British Columbia. British Columbia Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, British Columbia Wildlife Bulletin No. B-101. Available from: <http://www.env.gov.bc.ca/wld/documents/statusrpts/b101.pdf> (Accessed February 2014).
- COSEWIC. (2013). COSEWIC assessment and update status report on the Northern Goshawk *laingi* subspecies *Accipiter gentilis laingi* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 55 pp.
- Craig, G.R. (2002). Recommended buffer zones and seasonal restrictions for Colorado raptors. Colorado Division of Wildlife. Unpublished report.
- Crocker-Bedford, D.C. (1990). Goshawk reproduction and forest management. *Wildlife Society Bulletin* 18: 262-269.

- Crocker-Bedford, D.C. (1995). Northern goshawk reproduction relative to selection harvest in Arizona. *Journal of Raptor Research* 29: 42-43.
- Czembor, C. (2012). Northern Goshawk (*Accipiter gentilis*) Habitat Mapping Using Spot and Landsat Satellite Imagery. Unpublished report submitted to Parks Canada Agency, Vancouver. British Columbia.
- Daust, D., L. Kremsater, C. Apps, K. Brunt, A.E. Burger, K. Dunsworth, L. Dupuis, F. Doyle, P. Friele, T. Mahon, V. Michelfelder, E. McClaren, G. MacHutchon, B. Pollard, D. Seip, J.D. Steventon, and F.L. Waterhouse. (2010). Focal species at risk thresholds for BC's North and Central Coast: workshop proceedings. Unpublished report prepared for the Joint Coastal Land and Resource Forum Technical Liaison Committee. Integrated Land Management Bureau, Nanaimo, B.C. 104 pp.
- Daw, S.K., and DeStefano, S. (2001). Forest characteristics of northern goshawk nest stands and post-fledging areas in Oregon. *The Journal of Wildlife Management* 65(1): 59-65.
- Deal, J., and D. Mogensen (Western Forest Products). (2013). Commentary, literature review and home range spacing analysis. Submitted to Parks Canada Agency for October 2013 Northern Goshawk workshop. Unpublished and not peer reviewed.
- Desimone, S.M. and S. DeStefano. (2005). Temporal patterns of Northern Goshawk nest area occupancy and habitat: A retrospective analysis. *Journal of Raptor Research* 39(3): 310-323.
- Doyle, F.I. (2005). Breeding success of the Goshawk (*A. gentilis laingi*) on Haida Gwaii/Queen Charlotte Islands 2005: is the population continuing to decline? Wildlife Dynamics Consulting, Telkwa, British Columbia. Unpublished report.
- Doyle, F.I. (2006). Managing for goshawks on the North Coast. Wildlife Dynamics Consulting, Telkwa, British Columbia. Unpublished report.
- Environment Canada. (2014). Avoidance guidelines (for disturbance). Available from: <http://www.ec.gc.ca/paom-itmb/default.asp?lang=En&n=AB36A082-1> (Accessed April 2015).
- Finn, S.P., J.M. Marzluff, and D.E. Varland. (2002). Effects of landscape and local habitat attributes on Northern Goshawk site occupancy in western Washington. *Forest Science* 48(2):427-436.
- Franklin, I.R. (1980). Evolutionary change in small populations. *In*: Soulé, M.E., Wilcox, B.A. (Eds.), *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland, MA, pp. 135-149.
- Good, R.E. (1998). Factors affecting the relative use of Northern Goshawk (*Accipiter gentilis*) kill areas in southcentral Wyoming. M.S. Thesis. University of Wyoming, Laramie, WY. 153p.

- Government of Canada. (2016). Government of Canada. 2016. Policy on Survival and Recovery [Proposed]. Species at Risk Act: Policies and Guidelines Series. Government of Canada, Ottawa. 8 pp. Available from: http://www.sararegistry.gc.ca/document/default_e.cfm?documentID=2985 (Accessed April 2018).
- Greenwald, D.N., D.C. Crocker-Bedford, L. Broberg, K.F. Suckling, and T. Tibbitts. (2005). A review of Northern Goshawk habitat selection in the home range and implications for forest management in the western United States. *Wildlife Society Bulletin* 33(1): 120-128.
- Grubb, T., L. Pater, A. Gatto, and D. Delaney. (2012). Response of nesting northern Goshawks to logging truck noise Kaibab National Forest, Arizona. *Journal of the Acoustical Society of America* 132(3): p2063.
- Hargis, C. D., C. McCarthy, and R.D. Perloff. (1994). Home ranges and habitats of Northern Goshawks in eastern California. *Studies in Avian Biology* 16: 66-74.
- Harrower, W.L., K.W. Larsen, and K.A Stuart-Smith. (2010). Movements and resource selection of fledgling Goshawks in montane forests of southeastern British Columbia. *The Journal of Wildlife Management* 74(8): 1768-1775.
- Hockin, D., M. Ounsted, M. Gorman, D. Hill, V. Keller and M.A. Barker. (1992). Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. *Journal of Environmental Management* 36: 253-286.
- Ingraldi, M.E. (2001). Demography and habitat characteristics of Northern Goshawks on the Apache-Sitgreaves National Forest 1993-2000. Arizona Game and Fish Department, Federal Aid Final Report, Phoenix. Unpublished report.
- Iverson, G.C., G.D. Hayward, K. Titus, E. DeGayner, R.E. Lowell, D.C. Crocker-Bedford, P.F. Schempt, and J. Lindell. (1996). Conservation assessment for the Northern Goshawk in southeast Alaska. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-387.
- Jamieson, I.G., and F.W. Allendorf. (2012). How does the 50/500 rule apply to MVPs? *Trends in Ecology and Evolution* 27(10): 578-584.
- Kennedy, P.L., J.M. Ward, G.A. Rinker, and J.A. Gessamen. (1994). Post-fledging areas in Northern Goshawk home ranges. *Studies in Avian Biology* 16: 75-82.
- Kenward, R.E. (2006). *The Goshawk*. T. and A.D. Poyser, London.
- MacKinnon, A., D. Meidinger, and K. Klinka. (1992). Use of the bigeoclimatic ecosystem classification system in British Columbia. *For. Chron.* 68:100-120.

- Maguire, L., and D. Call. (1993). Population viability analysis of northern goshawks (*Accipiter gentilis*) on the North Kaibab Ranger District, Arizona. Contract No. G10076-A, Arizona. Game and Fish Department, Phoenix, Arizona, USA. Unpublished report.
- Mahon, T. (2009). Northern Goshawks in west-central British Columbia: 10-year project summary. Bulkley Valley Centre for Natural Resources Research and Management, Smithers, British Columbia. Unpublished report.
- Mahon, T., E. McClaren, and F. Doyle. (2008). Parameterization of the Northern Goshawk (*Accipiter gentilis laingi*) habitat model for coastal British Columbia. Produced for the Northern Goshawk Recovery Team and Habitat Recovery Implementation Group. Draft. Unpublished report.
- Mahon, T., E. McClaren, and F. Doyle. (2013). Recent analyses produced in support of development of Best Management Practices guidelines. Submitted for Parks Canada's October 2013 Northern Goshawk workshop. Unpublished and not peer reviewed.
- Mahon, T., E. McClaren, and F. Doyle. (2015). Northern Goshawk (*Accipiter gentilis laingi*) Habitat Models for Coastal British Columbia. Nesting and Foraging Habitat Suitability Models and Territory Analysis Model. Produced for the Northern Goshawk Recovery Team and Habitat Recovery Implementation Group. Draft. Unpublished report.
- Manning, T. (2012). Maintaining the integrity of Northern Goshawk nesting and post-fledging areas in the Ecosystem Based Management Area of coastal British Columbia: guidance for forest professionals. Coast Forest Conservation Initiative. Unpublished report.
- Manning, T., and P. Chytk. (2008). Northern goshawk nest territory monitoring. Western Forest Products TFL 37, Woss, British Columbia. Unpublished report.
- Manning, T., and P. Chytk. (2018). Analysis of Northern Goshawk Home Range Spacing on the Coast of British Columbia. Unpublished report prepared for the Parks Canada Agency, Vancouver, British Columbia.
- McClaren, E.L. (2005). Northern Goshawk (*Accipiter gentilis laingi*) population inventory summary for Vancouver Island, British Columbia 1994-2002. British Columbia Ministry of Environment, Victoria, British Columbia. Wildl. Bull. No. B-117.
- McClaren, E.L. (2009). Northern Goshawk 2009 territory analysis summary. Unpublished report and model outputs. British Columbia Ministry of Environment, Campbell River.
- McClaren, E.L., and C.L. Pendergast. (2003). Relationship between forest age class distribution around Northern Goshawk nests and occupancy and nest productivity

- patterns at three spatial scales. B.C. Ministry of Water, Land and Air Protection, Nanaimo, BC. 8 pp. Unpublished report.
- McClaren, E.L., P.L. Kennedy, and D.D. Doyle. (2005). Northern Goshawk (*Accipiter gentilis laingi*) post-fledging areas on Vancouver Island, British Columbia. *Journal of Raptor Research* 39: 253–263.
- McClaren, E.L., T. Mahon, F.I. Doyle, and W.L. Harrower. (2015). Science-Based Guidelines for Managing Northern Goshawk Breeding Areas in Coastal British Columbia. *Journal of Ecosystems and Management* 15(2):1–91. Published by the Journal of Ecosystems and Management: Available from: <http://jem-online.org/index.php/jem/article/viewFile/576/506> (Accessed November 2016).
- McLaughlin, R.T. (2002). Northern Goshawk nest monitoring in BR 128, Sproat Lake timberlands. Nanaimo Woodlands, Nanaimo, British Columbia. Unpublished Report.
- McGrath, M.T., S. DeStefano, R.A. Riggs, L.L. Irwin, and G.J. Roloff. (2003). Spatially explicit influences on Northern Goshawk nesting habitat in the interior Pacific Northwest. *Wildlife Monographs*, 1-63.
- MoFLNRO and MoE (Ministry of Forests, Lands, and Natural Resource Operations and Ministry of Environment). (2013). Management plan for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) in British Columbia. British Columbia Ministry of Forests, Lands, and Natural Resource Operations and British Columbia Ministry of Environment, Victoria, British Columbia. 30 pp.
- MoFLNRORD (British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development). 2018. Implementation plan for Northern Goshawk, *laingi* subspecies in British Columbia. Victoria, British Columbia. 23 pp. Available from: <https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/species-ecosystems-at-risk/implementation> (Accessed April 2018).
- MWLAP (Ministry of Water, Land and Air Protection). (2004). Queen Charlotte Goshawk. Accounts and Measures for managing Identified Wildlife, Volume 1. Victoria, British Columbia.
- Moser, B.W. (2009). Space use and ecology of goshawks in northern Idaho. Doctoral dissertation, University of Idaho, ID.
- Moser, B.W., and E.O. Garton. (2009). Short-term effects of timber harvest and weather on Northern Goshawk reproduction in northern Idaho. *Journal of Raptor Research*, 43(1): 1-10.
- NGRT (Northern Goshawk *Accipiter gentilis laingi* Recovery Team). (2008). Recovery strategy for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) in British Columbia. British Columbia Ministry of Environment, Victoria, B.C. Available from:

- http://www.env.gov.bc.ca/wld/documents/recovery/rcvrystrat/northern_goshawk_rcvry_strat_200508.pdf (Accessed February 2014).
- Orians, G.H., N.E. Pearson. (1979). On the theory of central place foraging. *In*: Horn, D.J., R.D. Mitchell, and G.R. Stairs. (Eds.), *Analysis of Ecological Systems*. The Ohio State University Press, Columbus, pp. 154–177.
- Patla, S.M. (1997). Nesting ecology and habitat of the Northern Goshawk in undisturbed and timber harvest areas on the Targhee National Forest, Greater Yellowstone Ecosystem. Doctoral dissertation, Idaho State University, ID.
- Patla, S.M. (2005). Monitoring results of Northern Goshawk nesting areas in the greater Yellowstone ecosystem: is decline in occupancy related to habitat change? *Journal of Raptor Research* 39(3): 324-333.
- Penteriani, V., and Faivre, B. (2001). Effects of harvesting timber stands on goshawk nesting in two European areas. *Biological Conservation* 101(2): 211-216.
- Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce, G. Goodwin, R. Smith, and E.L. Fisher. (1992). Management recommendations for the Northern Goshawk in the southwestern United States. RMRS-GTR-217.
- Rutz, C., R.G. Bulsma, M. Marquiss, and R.E. Kenward. (2006). Population limitation in the northern goshawk in Europe: a review with case studies. *Studies in Avian Biology* 31: 158-197.
- Smith, J.R., and R.G. Vennesland. (2013). Northern Goshawk habitat and territory modeling results. Unpublished report and model outputs. Prepared by Cortex Consulting for Parks Canada Agency, Vancouver, British Columbia.
- Sonsthagen, S.A., E.L. McClaren, F.I. Doyle, K. Titus, G.K. Sage, R.E. Wilson, J.R. Gust, and S.L. Talbot. (2012). Identification of metapopulation dynamics among Northern Goshawks of the Alexander Archipelago, Alaska, and Coastal British Columbia. *Conservation Genetics*. DOI: 10.1007/s10592-012-0352-z.
- Soulé, M.E. (1980). Thresholds for survival: maintaining fitness and evolutionary potential. *In*: Soulé, M.E., Wilcox, B.A. (Eds.), *Conservation Biology: An Evolutionary-Ecological Perspective*. Sinauer, Sunderland, MA, pp. 151-169.
- Squires, J.R., and P.L. Kennedy. (2006). Northern Goshawk ecology: an assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology* 31: 08-62.
- Squires, J.R. and R.T. Reynolds. (1997). Northern Goshawk (*Accipiter gentilis*). *In* A. Poole and F. Gill, editors. *Birds of North America*, No. 298. The Academy of Natural Sciences, Philadelphia, PA and Am. Ornithologists' Union, Washington, D.C.

Steventon, J.D. (2012a). A heuristic Population Viability Analysis for the Northern Goshawk (*Accipiter gentilis laingi*) of coastal British Columbia. Unpublished report to the British Columbia Northern Goshawk Recovery Team (February 2012).

Steventon, J.D. (2012b). A heuristic Population Viability Analysis for the Northern Goshawk (*Accipiter gentilis laingi*) of coastal British Columbia – summary of key results and interpretations. Unpublished report to the British Columbia Northern Goshawk Recovery Team (August 2012).

Stuart-Smith, A.K., W.L. Harrower, T. Mahon, E.L. McClaren, and F.I. Doyle. (2012). A scientific basis for managing northern goshawk breeding areas in the Interior of British Columbia: Best management practices. FORREX Forum for Research and Extension in Natural Resources, Kamloops, British Columbia. FORREX Series 29.

Talbot, S.L., S.A. Sonsthagen and G.K. Sage. (2011). Genetic relationships among goshawks of British Columbia and Alaska. U.S. Geological Survey, Anchorage, AK. 23 pp. Unpublished report.

Toyne, E.P. (1997). Nesting chronology of Northern Goshawks (*Accipiter gentilis*) in Wales: implications for forest management. *Forestry* 70: 121-127.

USFWS (U.S. Fish and Wildlife Service). (2007). Queen Charlotte Goshawk status review. USFWS, Alaska Region, Juneau Fish and Wildlife Field Office, Juneau, AK. 173 pp.

Vennesland, R.G. (2018). Review and analysis of studies on Northern Goshawk foraging habitat availability in known versus randomly generated home ranges on the coast of British Columbia. Unpublished report.

Vernier, P.R., and F.L. Bunnell. (2002). Habitat Associations of Northern Goshawk Nest Sites at Multiple Spatial Scales on Canfor's Forest Tenure on Vancouver Island. Report for Canadian Forest Products Ltd.

Ward, L. Z., D.K. Ward, and T.J. Tibbits. (1992). Canopy density analysis at goshawk nesting territories on the North Kaibab Ranger District, Kaibab National Forest. Arizona Game and Fish Department, Nongame and Endangered Wildlife Program. As described in Greenwald *et al.* (1995).

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Appendix A: Northern Goshawk Habitat Suitability Index Models

Mahon *et al.* (2008, 2015) created Habitat Suitability Index (HSI) models for Northern Goshawk to aid in the identification of suitable habitat for Northern Goshawk. The model applications and output were described in Smith and Sutherland (2008). Habitat was rated by the models as highly suitable (HSI > 0.75), moderately suitable (HSI = 0.75-0.5), of low suitability (HSI < 0.5, or not suitable (HSI = 0).

This section provides an overview of the suitability models as per Mahon *et al.* (2015). The models are used to describe the biophysical attributes of critical habitat that is identified in this federal recovery strategy.

For critical habitat for breeding areas, model parameters included:

1. Stand age and height, where suitability increased linearly from lowest suitability (HSI = 0) below 40 years old and 14 m tall to highest suitability (HSI = 1) above 90 years old and/or 32 m tall. These estimates were based on habitat data collected around known nest areas on Haida Gwaii, the North Coast, and Vancouver Island. The model used an average of the ratings of these two variables because stand age and height are typically highly correlated.
2. Edge habitat, where the presence of a 'hard' edge within 200 m of the nest area makes the habitat less suitable. A 'hard' forest edge was considered to occur where mature forest was adjacent to non-forested habitat or younger forest, and where the height difference between the two habitat types was > 15 m. The impact of the edge habitat varied with distance from the nest area (< 100 m or 100-200 m), and the type of edge habitat: anthropogenic (primarily forest harvesting) or natural (e.g., along lakes or marshes). The impact of edge habitat was considered more severe when it was closer to the nest area, and occurred through anthropogenic influence.
3. Forest composition, where stands dominated by Western Hemlock (*Tsuga heterophylla*), Sitka Spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*), Subalpine Fir (*Abies lasiocarpa*), Amabilis Fir (*Abies amabilis*), or mixed forest were considered most suitable; stands dominated by Western Redcedar (*Thuja plicata*), deciduous forest, or Lodgepole Pine (*Pinus contorta*), or with Lodgepole Pine or Yellow Cedar (*Chamaecyparis nootkatensis*) as a secondary species were considered moderately suitable; and pure stands of Western Redcedar, or stands dominated by Yellow Cedar were rated low suitability.
4. Elevation, where habitat at all elevations was considered potential breeding habitat if other suitable conditions existed. Overall habitat suitability declined slowly in a linear fashion from HSI = 1 below 400 m on Haida Gwaii, 600 m on the North Coast, and 800 m on the South Coast and Vancouver Island to a minimum of HSI = 0.5 at 1,300 m.
5. Slope, where habitat at all elevations was considered potential breeding habitat if other suitable conditions existed. Slopes < 30° were considered most suitable (HSI = 1), with a non-linear decrease in suitability to HSI = 0.5 at 90°.

6. Biogeoclimatic Ecosystem Classification (BEC) zone variant, where most BEC zone variants were considered to provide potential breeding habitat if other suitable conditions existed. The most suitable habitat was in the Coastal Douglas-Fir (CDF) and Coastal Western Hemlock (CWH) zones. Slightly lower ranked, but still of high suitability were the remaining CWH zone variants and the Mountain Hemlock (MH) zone. Engelmann Spruce – Subalpine Fir (ESSF) was of moderate suitability, and alpine tundra, alpine parkland, and ESSF parkland were all of low suitability.

The parameters were used in a habitat model that used a limiting factor, non-compensatory structure, where deficiencies in one parameter could not be compensated for by another parameter (Mahon *et al.* 2015).

For critical habitat for foraging areas, model parameters included:

1. Stand age and height, where the lowest score for foraging habitats was HSI = 0.3, acknowledging that younger forests can provide some suitability for foraging (e.g., Bloxton 2002). Suitability increased linearly from lowest suitability (HSI = 0.3) below 40 years old and 14 m tall to highest suitability (HSI = 1) above 90 years old and/or 32 m tall. The model used an average of the ratings of these two variables because stand age and height are typically highly correlated.
2. Forest composition, where all forest types have potential value as foraging habitat (lowest HSI = 0.6) if stand age and height were suitable. Stands where spruce is the dominant or secondary species, where Douglas-fir or Amabilis Fir is dominant (except where Yellow Cedar or Lodgepole Pine are secondary species) were considered most suitable. Stands dominated by Western Redcedar (> 80%) or Lodgepole Pine, or stands where Yellow Cedar was the dominant or secondary species were considered of moderate suitability.
3. BEC variant, where most BEC variants were considered to have the potential to provide foraging habitat (Lowest HSI = 0.4) if other suitable conditions existed. The most suitable habitat was in the CDF and for some variants in CWH. The remaining CWH variants, MH and some variants of ESSF were ranked as moderate suitability, and alpine tundra was ranked as low suitability.
4. Non-productive and non-forested habitats, where habitats such as wetlands and bogs, non-productive brush, and alpine potentially provide foraging habitat for Northern Goshawks. All vegetated polygons with a non-productive or non-forested descriptor (e.g., alpine, alpine forest, swamp, non-productive brush, clearing, meadow, open range, non-productive burn, or non-commercial brush) were assigned a low suitability rating (HSI = 0.3). Non-vegetated polygons with a non-productive or non-forested descriptor (e.g., rock, gravel, sand, clay bank, lake, gravel bar, river, or human development) were assigned a nil suitability rating (HSI = 0).

The foraging habitat model, like the nesting (breeding) habitat model, used a limiting factor, non-compensatory structure, where deficiencies in one parameter could not be compensated for by another parameter (Mahon *et al.* 2015).

The performance of the nesting (breeding) and foraging models was assessed in each conservation region using formal accuracy assessment procedures determined prior to field work. The accuracy assessment compared model predictions to field ratings assessed by Northern Goshawk experts at each location. Accuracy scoring used two methods (for different ways the model outputs might be used) and was conducted at three scales (site, stand and regional scales), to account for potential spatial accuracy issues and to advise on management activities that may be conducted at those scales. Using the primary scoring method (based on the difference between the model and field ratings) and the stand-level scale, the nesting model averaged 82% accuracy and overestimated suitability by 0.01 – 0.09 HSI units (depending on conservation region). The foraging model averaged 85% accuracy and underestimated suitability by 0.04-0.06 HSI units. Accuracy scores and patterns of bias were consistent across regions, suggesting that the models performed fairly robustly across the coast. Model errors appeared to be largely driven by errors in forest cover data, which has two significant implications: 1) errors in the underlying data limit potential model revisions to improve performance, and 2) use of the model outputs should be consistent with generally accepted practices and limitations associated with using forest cover data for other forest and habitat management activities. Although the accuracy of the models exceeds the a priori target of 80% initial set by the provincial recovery team, precautionary use of model outputs is recommended, including verification of model predictions via ground truthing or aerial imagery.

Appendix B: Amount and Location of Critical Habitat

Included in this appendix are maps showing the layout of all conservation regions and sub-regions (Figure B-1) and the location of critical habitat for Northern Goshawk, *laingi* subspecies in each region or sub-region (Figures B-2 to B-6), and a table (Table B-1) that lists the home ranges within which critical habitat is identified for Northern Goshawk, the conservation region or sub-region in which the home range occurs, and the amount of area within which critical habitat is found for breeding and foraging.

Home ranges with small amounts of critical habitat may not be obvious on the maps included in this appendix, so it is recommended that those with interests on the land base acquire more detailed mapping resources (e.g., GIS spatial layers).

For access to detailed mapping resources and supporting documents outlining the methods used for critical habitat in this strategy, please see the contact information listed for Northern Goshawk, *laingi* subspecies on the Species at Risk Public Registry: <http://www.registrelep-sararegistry.gc.ca/>.

Figure B-1. The Northern Goshawk *laingi* subspecies conservation regions and sub-regions within which home ranges occur and where critical habitat is identified on the coast of British Columbia



Figure B-2. Critical habitat for Northern Goshawk *laingi* subspecies in the Haida Gwaii Conservation Region.

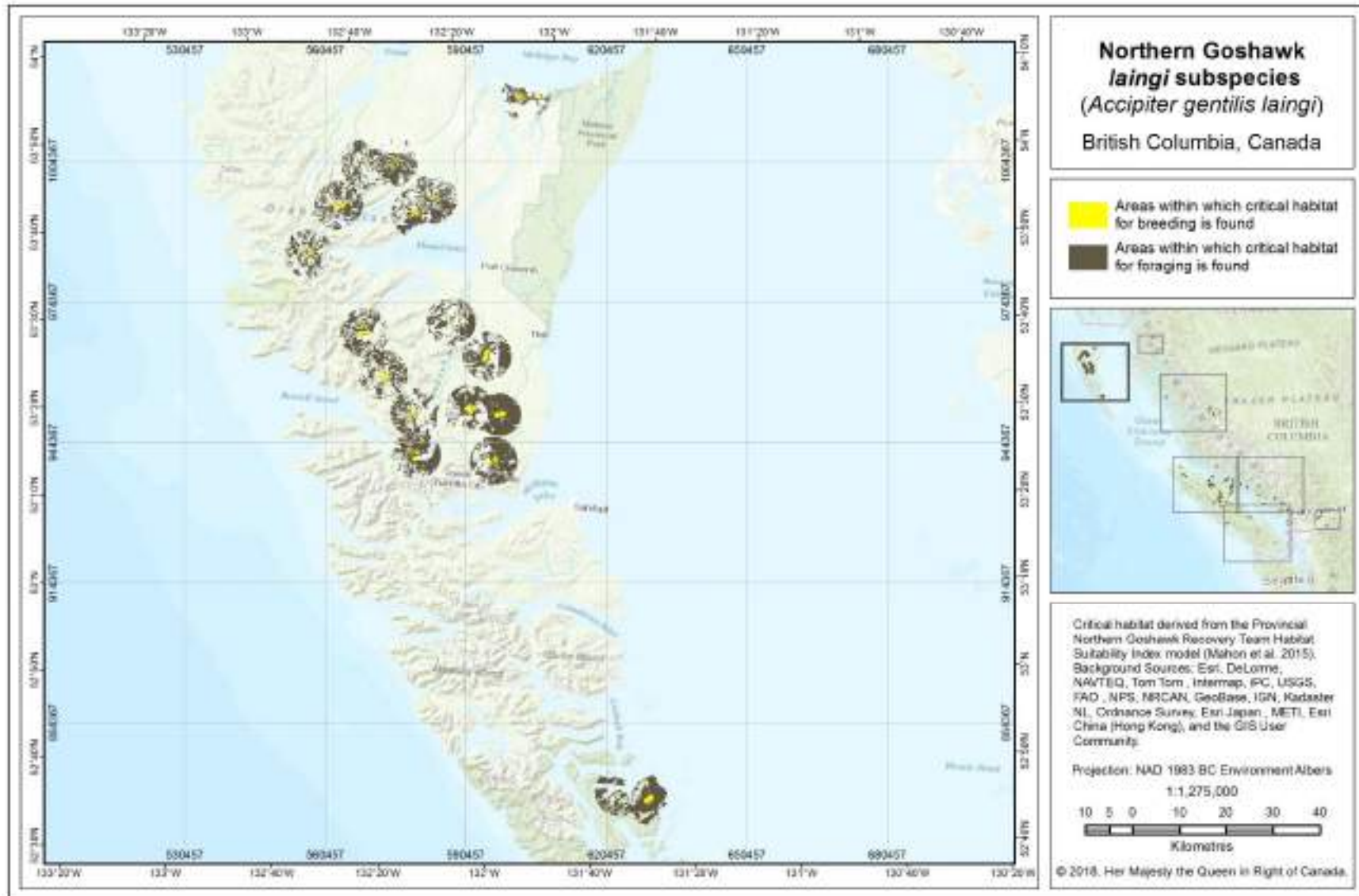


Figure B-3. Critical habitat for Northern Goshawk *laingi* subspecies in the northern reaches of the North Coast Conservation Region and the North Coast–Bella Coola sub-region.

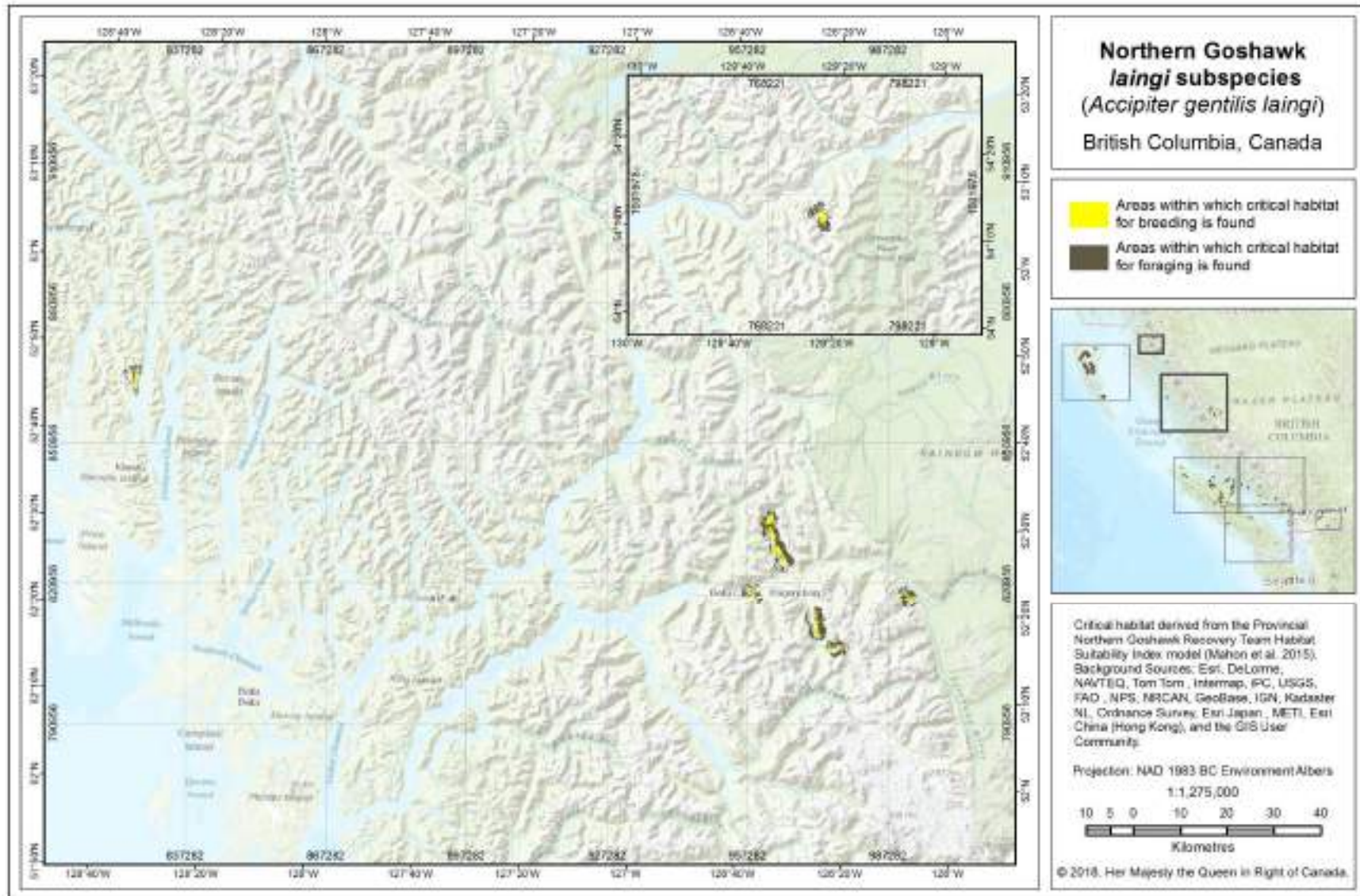


Figure B-4. Critical habitat for Northern Goshawk, *laingi* subspecies in the North Coast and Vancouver Island Conservation Regions and the Coastal Dry Ecosystem sub-region.

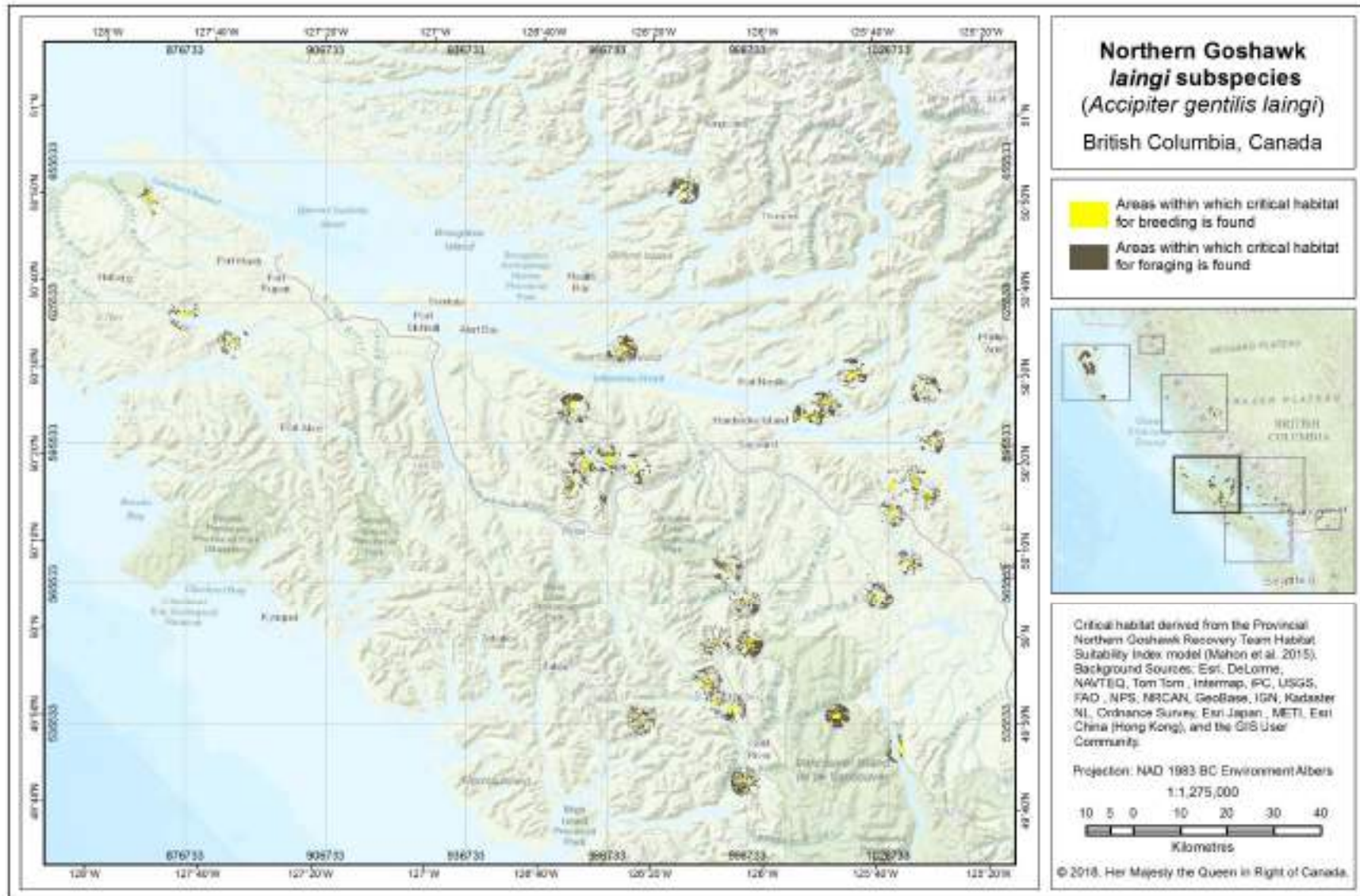


Figure B-5. Critical habitat for Northern Goshawk, *laingi* subspecies in the South Coast and Vancouver Island Conservation Regions and the Coastal Dry Ecosystem Zone sub-region.

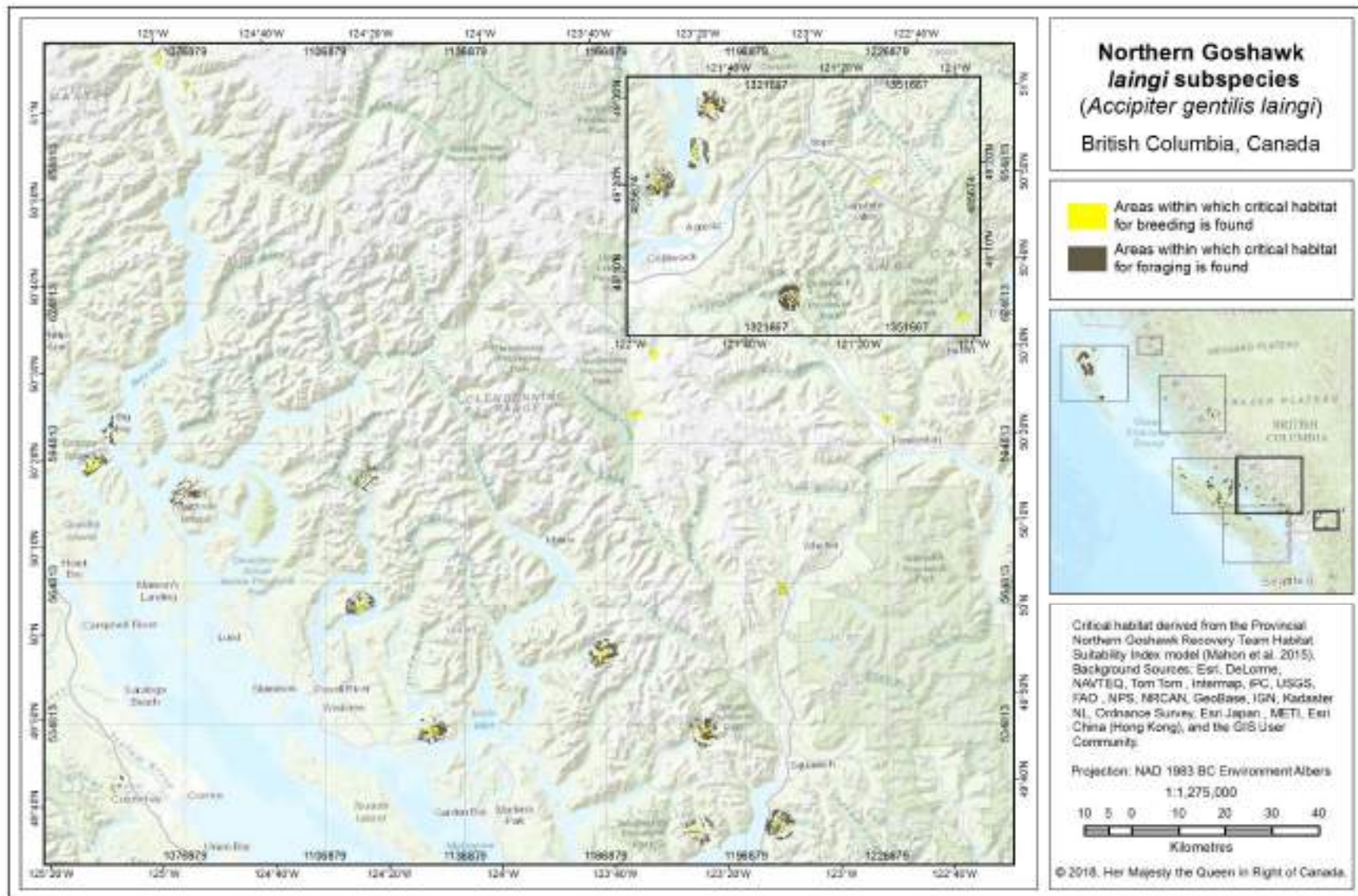


Figure B-6. Critical habitat for Northern Goshawk, *laingi* subspecies on the southern reaches of the Vancouver Island and South Coast Conservation Regions and the Coastal Dry Ecosystem Zone sub-region.

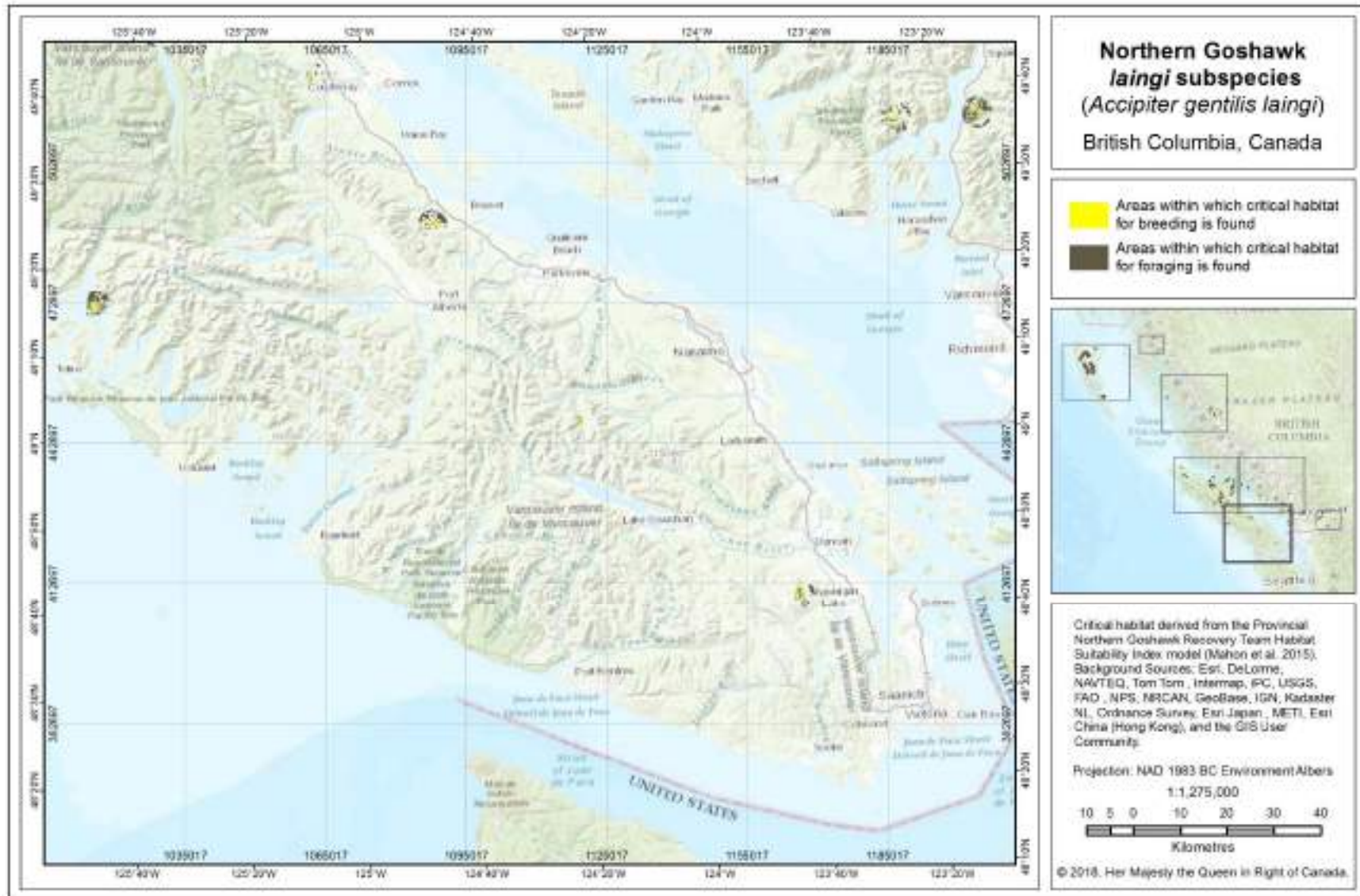


Table B-1. Location and amount of area within which critical habitat for breeding and foraging is found in each home range (n=110 home ranges).

Home Range	Conservation Region or Sub-region	Figure No.	Nest Centroid ¹ X Coordinate	Nest Centroid ¹ Y Coordinate	Amount of area within which critical habitat for breeding is found (ha)	Amount of area within which critical habitat for foraging is found (ha)
Ain*	Haida Gwaii	Figure B-2	579719.8969	993378.4499	174	3942
Black Bear	Haida Gwaii	Figure B-2	594981.7197	962828.0109	246	4770
Bonanza	Haida Gwaii	Figure B-2	572769.3218	958805.9823	200	3855
Crease	Haida Gwaii	Figure B-2	563268.7205	994962.4386	201	4333
Datlamen	Haida Gwaii	Figure B-2	568791.1792	967757.4813	240	4118
Delkatla*	Haida Gwaii	Figure B-2	603100.3057	1018036.7313	218	1799
Demon	Haida Gwaii	Figure B-2	579574.5056	950723.1420	168	3752
Florence Creek	Haida Gwaii	Figure B-2	587318.8681	970138.7639	58	3892
Ian	Haida Gwaii	Figure B-2	556785.6519	984715.2892	129	3120
Ian 990	Haida Gwaii	Figure B-2	574972.7504	1004244.6332	137	4166
Lignite Creek	Haida Gwaii	Figure B-2	568743.3114	1003845.7744	34	3692
Sandy Creek	Haida Gwaii	Figure B-2	623284.7293	869704.1455	30	3226
Skowkona	Haida Gwaii	Figure B-2	596290.3259	940449.6442	192	5564
Survey	Haida Gwaii	Figure B-2	597709.4306	950365.7403	223	5563
Three Mile	Haida Gwaii	Figure B-2	591203.7414	951475.4417	242	4397
Upper Hancock	Haida Gwaii	Figure B-2	583478.4479	996422.8382	88	4531
Windy Bay	Haida Gwaii	Figure B-2	629501.0558	867975.5473	250	4408
Yakoun Lake	Haida Gwaii	Figure B-2	579828.6504	941730.3671	202	4991
Alder Creek	North Coast	Figure B-3 (Inset)	780010.3879	1027138.0996	229	1282
Brooks Bay*	North Coast	Figure B-4	1034804.3224	606943.6762	69	1129
Forward Harbour	North Coast	Figure B-4	1019053.3336	610362.5647	220	1251
Hardwicke Island 1	North Coast	Figure B-4	1009660.1727	601173.4269	239	1214
Hardwicke Island 2	North Coast	Figure B-4	1013691.8286	604384.1789	168	1316

Home Range	Conservation Region or Sub-region	Figure No.	Nest Centroid ¹ X Coordinate	Nest Centroid ¹ Y Coordinate	Amount of area within which critical habitat for breeding is found (ha)	Amount of area within which critical habitat for foraging is found (ha)
Kwatzi Bay	North Coast	Figure B-4	983029.2161	649360.3208	115	1482
Princess Royal Is.	North Coast	Figure B-3	826765.3134	864309.0561	160	742
West Cracroft	North Coast	Figure B-4	969937.9639	615444.6177	173	1537
Nusatsum East	North Coast-Bella Coola	Figure B-3	971881.2708	813567.6396	159	907
Nusatsum North	North Coast-Bella Coola	Figure B-3	972346.6560	810585.9015	182	907
Nusatsum South UK & Nusatsum South	North Coast-Bella Coola	Figure B-3	976538.8181	807313.4263	109	824
Saloompt Central	North Coast-Bella Coola	Figure B-3	962467.5543	831660.8268	225	907
Saloompt Central 2	North Coast-Bella Coola	Figure B-3	962026.0616	834446.4349	224	907
Saloompt fireblock	North Coast-Bella Coola	Figure B-3	964962.8623	825598.2900	91	907
Saloompt South UK	North Coast-Bella Coola	Figure B-3	963651.3121	828087.4956	245	907
Snootli Creek	North Coast-Bella Coola	Figure B-3	958391.9576	818639.7902	134	730
Talchako*	North Coast-Bella Coola	Figure B-3	991507.5056	818124.8921	152	899
Anderson Lake*	Vancouver Island		1103524.7071	407389.5990	0	0
Cervus Creek	Vancouver Island	Figure B-4	1015970.4105	537155.9172	191	1668
China Creek*	Vancouver Island	Figure B-6	1102099.3472	458981.3824	0	1
Claude Elliot*	Vancouver Island	Figure B-4	959229.1349	586901.6852	88	966
Clayoquot Sound	Vancouver Island	Figure B-6	1016040.1622	471704.8101	163	1193
Colony Lakes*	Vancouver Island	Figure B-4	887100.5553	617041.7518	157	852
Consort Creek	Vancouver Island	Figure B-4	996040.6297	561333.9118	133	1083
Conuma River	Vancouver Island	Figure B-4	974105.6303	536592.1861	125	1239
Derby	Vancouver Island	Figure B-4	959597.1157	602765.5632	189	1586
Elbow Creek	Vancouver Island	Figure B-4	997128.4559	552448.1705	251	1668
Garbage Creek*	Vancouver Island		1140076.2676	398006.0272	0	0
Gerald Creek	Vancouver Island	Figure B-4	992174.8933	568626.9231	58	917

Home Range	Conservation Region or Sub-region	Figure No.	Nest Centroid ¹ X Coordinate	Nest Centroid ¹ Y Coordinate	Amount of area within which critical habitat for breeding is found (ha)	Amount of area within which critical habitat for foraging is found (ha)
Loon Lake*	Vancouver Island		938457.2223	581169.7360	0	0
Lukwa*	Vancouver Island	Figure B-4	963400.5490	582515.8690	0	142
Mt. Edinburgh*	Vancouver Island		1115739.1474	403760.6305	0	0
Nadira 700*	Vancouver Island		1101651.9915	442404.9643	0	0
Nahmint*	Vancouver Island		1074261.1158	459163.0774	0	0
Norton Point	Vancouver Island	Figure B-4	876578.1574	622966.7631	141	720
Oktwanch	Vancouver Island	Figure B-4	987969.1223	544435.6589	237	1206
Shushartie Bay	Vancouver Island	Figure B-4	869217.8035	647221.2375	211	540
Tlatlos	Vancouver Island	Figure B-4	972586.5138	589770.3571	101	896
Tsitika	Vancouver Island	Figure B-4	967344.7598	592241.6515	236	1012
Tsitika West	Vancouver Island	Figure B-4	961876.3810	591137.0466	217	1213
Twaddle Lake	Vancouver Island	Figure B-4	989901.0254	553172.9849	77	909
Ucona River	Vancouver Island	Figure B-4	996337.5994	523154.4043	196	1668
Bear Creek	South Coast	Figure B-5 (Inset)	1309685.7723	504829.2255	106	1517
Brew Creek*	South Coast	Figure B-5	1204820.4341	564067.8197	244	244
Chehalis Woodlot*	South Coast	Figure B-5 (Inset)	1298797.1887	488336.9429	157	1557
Chilliwack River (Nesaquatch)*	South Coast	Figure B-5 (Inset)	1327127.8577	463834.8952	94	1622
Furry Creek	South Coast	Figure B-5 & B-6	1204044.1164	513293.4597	134	1602
Goat Island	South Coast	Figure B-5	1114527.4825	559967.3462	233	1216
Harrison Lake	South Coast	Figure B-5 (Inset)	1306629.5217	494669.7475	173	1052
Homathco 2*	South Coast	Figure B-5	1076932.7714	672057.1100	113	113
Homathco 3*	South Coast	Figure B-5	1070806.5054	676802.2438	158	158
Lillooett River*	South Coast	Figure B-5	1227647.6666	599915.2614	160	160
McNab Creek	South Coast	Figure B-5 & B-6	1186799.4532	512130.1729	116	876

Home Range	Conservation Region or Sub-region	Figure No.	Nest Centroid ¹ X Coordinate	Nest Centroid ¹ Y Coordinate	Amount of area within which critical habitat for breeding is found (ha)	Amount of area within which critical habitat for foraging is found (ha)
PD 203	South Coast	Figure B-5	1114996.7024	588024.7513	96	754
Red Tusk Creek	South Coast	Figure B-5	1187752.6331	533140.7597	155	1417
Saltery Bay ST048	South Coast	Figure B-5	1129506.8923	533172.5606	216	1292
Skyline Trail*	South Coast	Figure B-5 (Inset)	1363724.9570	459869.8328	202	202
Stewart Island*	South Coast	Figure B-5	1062241.3557	597705.6799	51	377
Upper Elaho 1*	South Coast	Figure B-5	1173620.8009	601067.6571	237	237
Upper Elaho 2*	South Coast	Figure B-5	1176749.2162	614111.1476	197	197
Vancouver River	South Coast	Figure B-5	1166242.5239	549840.4224	206	1544
West Hope Slide*	South Coast	Figure B-5 (Inset)	1344855.8261	488676.3399	131	131
West Rhodonda*	South Coast	Figure B-5	1076790.2281	583756.9857	0	977
Cook Creek*	Coastal Dry Ecosystem Zone	Figure B-6	1087884.5642	489409.7636	120	953
Corrigan Creek*	Coastal Dry Ecosystem Zone		1095816.9584	448222.0686	0	0
Dorr Lake*	Coastal Dry Ecosystem Zone	Figure B-5	1057443.2592	590124.7865	262	998
Dove Creek*	Coastal Dry Ecosystem Zone	Figure B-5 & B-6	1061902.4989	520820.0879	72	126
East Thurlow	Coastal Dry Ecosystem Zone	Figure B-4	1035696.5886	595745.9221	108	860
Frost Lake*	Coastal Dry Ecosystem Zone		960057.0204	572123.4096	0	0
Gold Park	Coastal Dry Ecosystem Zone	Figure B-4	993499.4977	538730.9011	181	1092
Great Central Lake B*	Coastal Dry Ecosystem Zone		1063639.4443	479021.1315	0	0
Green River*	Coastal Dry Ecosystem Zone	Figure B-6	1118958.3650	447840.5510	97	97
Hoomak Lake*	Coastal Dry Ecosystem Zone		962712.0718	575944.2790	0	0
John Road*	Coastal Dry Ecosystem Zone		964493.2468	566616.3805	0	0
Kaipit Road*	Coastal Dry Ecosystem Zone		945297.0429	579613.7835	0	0
Kelvin Creek*	Coastal Dry Ecosystem Zone	Figure B-6	1166322.2959	410595.2664	129	535
Klaklakama*	Coastal Dry Ecosystem Zone		966117.0030	572162.1581	0	0

Home Range	Conservation Region or Sub-region	Figure No.	Nest Centroid ¹ X Coordinate	Nest Centroid ¹ Y Coordinate	Amount of area within which critical habitat for breeding is found (ha)	Amount of area within which critical habitat for foraging is found (ha)
Lower Stella	Coastal Dry Ecosystem Zone	Figure B-4	1032259.3585	587667.0608	205	849
Lukwa South (CT060)*	Coastal Dry Ecosystem Zone	Figure B-4	960320.7264	578835.7102	0	8
Lupin Falls*	Coastal Dry Ecosystem Zone	Figure B-4	1029044.7493	530181.9554	181	658
Mclaughlin*	Coastal Dry Ecosystem Zone		1100126.6612	461569.4505	0	0
Muchalat Lake	Coastal Dry Ecosystem Zone	Figure B-4	989772.4974	540176.7431	109	696
Museum*	Coastal Dry Ecosystem Zone		1096154.8869	453041.9702	0	0
Paterson Lake	Coastal Dry Ecosystem Zone	Figure B-4	1024965.4565	562773.3080	118	1279
Pye Lake	Coastal Dry Ecosystem Zone	Figure B-4	1027736.9567	586671.3140	198	478
Roberts Lake	Coastal Dry Ecosystem Zone	Figure B-4	1027583.8842	580547.1916	191	885
Rona Loop*	Coastal Dry Ecosystem Zone		956858.4213	576098.5124	0	0
Surprise Lake	Coastal Dry Ecosystem Zone	Figure B-4	1031117.7888	569998.6294	114	878
Thomas Creek*	Coastal Dry Ecosystem Zone		1092216.8359	452181.4872	0	0
Toad Road*	Coastal Dry Ecosystem Zone		950164.9709	579225.5568	0	0
Upper Stella	Coastal Dry Ecosystem Zone	Figure B-4	1034864.6394	584283.7026	188	930
Vernon Ridge*	Coastal Dry Ecosystem Zone		968732.6489	561105.8301	0	0

¹ Nest centroid is the centroid of all known nest and supplementary nest locations for a breeding home range.

*Some critical habitat has not been identified due to insufficient available information or ongoing cooperation and consultation (see schedule of studies in Table 3).

**Part 2 – *Recovery Strategy for the Northern Goshawk, laingi*
subspecies (Accipiter gentilis laingi) in British Columbia,
prepared by the Northern Goshawk *Accipiter gentilis laingi*
Recovery Team for the British Columbia Ministry of
Environment**

Recovery Strategy for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) in British Columbia



Prepared by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team



Ministry of
Environment

April 2008

About the British Columbia Recovery Strategy Series

This series presents the recovery strategies that are prepared as advice to the Province of British Columbia on the general strategic approach required to recover species at risk. The Province prepares recovery strategies to meet its commitments to recover species at risk under the *Accord for the Protection of Species at Risk in Canada*, and the *Canada – British Columbia Agreement on Species at Risk*.

What is recovery?

Species at risk recovery is the process by which the decline of an endangered, threatened, or extirpated species is arrested or reversed, and threats are removed or reduced to improve the likelihood of a species' persistence in the wild.

What is a recovery strategy?

A recovery strategy represents the best available scientific knowledge on what is required to achieve recovery of a species or ecosystem. A recovery strategy outlines what is and what is not known about a species or ecosystem; it also identifies threats to the species or ecosystem, and what should be done to mitigate those threats. Recovery strategies set recovery goals and objectives, and recommend approaches to recover the species or ecosystem.

Recovery strategies are usually prepared by a recovery team with members from agencies responsible for the management of the species or ecosystem, experts from other agencies, universities, conservation groups, aboriginal groups, and stakeholder groups as appropriate.

What's next?

In most cases, one or more action plan(s) will be developed to define and guide implementation of the recovery strategy. Action plans include more detailed information about what needs to be done to meet the objectives of the recovery strategy. However, the recovery strategy provides valuable information on threats to the species and their recovery needs that may be used by individuals, communities, land users, and conservationists interested in species at risk recovery.

For more information

To learn more about species at risk recovery in British Columbia, please visit the Ministry of Environment Recovery Planning webpage at:

<<http://www.env.gov.bc.ca/wld/recoveryplans/rcvry1.htm>>

**Recovery Strategy for the Northern Goshawk, *laingi* subspecies
(*Accipiter gentilis laingi*) in British Columbia**

Prepared by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team

April 2008

Recommended citation

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Cover illustration/photograph

Mike Stini. Adult female Northern Goshawk (*Accipiter gentilis laingi*) on Vancouver Island, British Columbia.

Additional copies

Additional copies can be downloaded from the B.C. Ministry of Environment Recovery Planning webpage at:

<<http://www.env.gov.bc.ca/wld/recoveryplans/rcvry1.htm>>

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Disclaimer

This recovery strategy has been prepared by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team, as advice to the responsible jurisdictions and organizations that may be involved in recovering the species. The British Columbia Ministry of Environment has received this advice as part of fulfilling its commitments under the *Accord for the Protection of Species at Risk in Canada*, and the *Canada – British Columbia Agreement on Species at Risk*.

This document identifies the recovery strategies that are deemed necessary, based on the best available scientific and traditional information, to recover Northern Goshawk, *laingi* subspecies, populations in British Columbia. Recovery actions to achieve the goals and objectives identified herein are subject to the priorities and budgetary constraints of participatory agencies and organizations. These goals, objectives, and recovery approaches may be modified in the future to accommodate new objectives and findings.

The responsible jurisdictions and all members of the recovery team have had an opportunity to review this document. However, this document does not necessarily represent the official positions of the agencies or the personal views of all individuals on the recovery team.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that may be involved in implementing the directions set out in this strategy. The Ministry of Environment encourages all British Columbians to participate in the recovery of the Northern Goshawk, *laingi* subspecies.

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RESPONSIBLE JURISDICTIONS

The recovery strategy for Northern Goshawk, *laingi* subspecies was developed by the Northern Goshawk *Accipiter gentilis laingi* Recovery Team on behalf of the Province of British Columbia.

Northern Goshawk *laingi* subspecies populations occur throughout coastal forests of British Columbia, including some provincial and national parks. The British Columbia Ministry of Environment is responsible for producing a recovery strategy for this species under the *Accord for the Protection of Species at Risk in Canada*. Parks Canada Agency and Environment Canada's Canadian Wildlife Service participated in the development of this recovery strategy. In addition, Northern Goshawk *laingi* subspecies occurs in southeast Alaska and Washington and so their populations are considered trans-boundary to the United States. The U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game also participated in the preparation of this recovery strategy.

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EXECUTIVE SUMMARY

The Northern Goshawk is a raven-sized predatory bird with short, rounded wings and a long tail. Immature birds differ from adults in their plumage colouration for the first 2 years, after which all individuals ≥ 3 years are indistinguishable. Two subspecies of Northern Goshawk reside in Canada: *Accipiter gentilis laingi* and *A. gentilis atricapillus*. They were formerly referred to as Queen Charlotte Goshawk and Northern Goshawk, respectively. Originally, separation of the two subspecies was based on size and plumage colour, with *A. gentilis laingi* being smaller and having darker colouration than *A. gentilis atricapillus*. More recently, preliminary results from genetic analyses suggest coastal populations may be genetically distinct from interior populations and this difference may be greatest for populations inhabiting Haida Gwaii (Queen Charlotte Islands), British Columbia (B.C.) — the location of the original *A. gentilis laingi* type specimen. The focus of this recovery strategy is on the Northern Goshawk *laingi* subspecies, although the recovery team has also included relevant literature from studies on *A. gentilis atricapillus* and European Goshawks (*A. gentilis gentilis*).

Accipiter gentilis laingi is listed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) because of its estimated small breeding population size (<1,000 mature individuals) and perceived threats to its habitat, primarily from forest harvesting. Population estimates and trends are uncertain for this subspecies because it breeds at low densities and can be difficult to detect. *Accipiter gentilis laingi*'s selection of relatively large amounts of mature and old forests for nesting and foraging has caused conservation biologists to raise concerns. This has challenged resource managers to balance coastal forest management for timber resources and the maintenance of healthy *A. gentilis laingi* populations.

Accipiter gentilis laingi occurs within the Northwest coast of North America. In the United States, *A. gentilis laingi* occurs within coastal areas of Alaska and Washington and possibly Oregon and California. Within Canada, 100% of the range of *A. gentilis laingi* occurs within B.C., where it inhabits Haida Gwaii/Queen Charlotte Islands; Vancouver Island and coastal islands between Vancouver Island and mainland B.C.; and portions of the coastal mainland, west of the Coast Mountains. The recovery team has mapped the range of *A. gentilis laingi* to follow the Coastal Western Hemlock biogeoclimatic zone maritime variants. The precise range boundaries are unclear and there is likely some overlap between *A. gentilis laingi* and *A. gentilis atricapillus* where coastal forests transition to interior forests. To mitigate threats and implement recovery actions, the recovery team has divided *A. gentilis laingi*'s range into six conservation regions: (1) southeast Alaska (SEAK); (2) Haida Gwaii (HG); (3) North Coast, B.C. (NC); (4) South Coast, B.C. (SC); (5) Vancouver Island (VI); and (6) Western Washington (WA). The recovery team did not include California and Oregon in conservation regions because the occurrence of *A. gentilis laingi* within these areas is less certain. This document is a Canadian recovery strategy, so only those conservation regions within Canada (HG, NC, SC, and VI) will be addressed in this strategy, although the development of this strategy was based on relevant data collected within the United States and Canada. Until more information is available through habitat suitability and supply modelling, it is thought that approximately 54% of this subspecies current range (based on total landmass) is within Canada. Within B.C., about 47% is within the NC Conservation Region, 27% within the VI Conservation Region, 17% within the SC Conservation Region, and 9% within the HG Conservation Region.

No data exist on the historic or current changes in the distribution of *A. gentilis laingi*. There is no evidence to suggest major range contractions have occurred; however, small portions of its range (ca. 5%) have been permanently lost as a result of clearing forest lands for urbanization and agriculture, primarily within the VI, SC, and WA Conservation Regions. Harvesting of mature and old forests throughout this subspecies' range, reduced rotation periods between harvests, and changes in distributions and composition of prey species (e.g., introduced species) have likely influenced the distribution patterns of *A. gentilis laingi* over the past century.

Current and historic estimates of population abundance for *A. gentilis laingi* are imprecise. Estimates of population trends are uncertain for this subspecies because nest areas are difficult to monitor (low detection rates, high annual variability in occupancy, large distance between alternative nests) and survivorship data are lacking. Therefore, most estimates of abundance are inferred from relationships between breeding success and habitat characteristics, rather than from population parameter estimates and population modelling. Using estimates for the number of nest areas, the density of adjacent breeding pairs, and known annual occupancy rates, the recovery team estimated the number of breeding pairs within each conservation region as: 261–336 for SEAK, 48 for WA, 10–18 for HG, 71–75 for NC, 106–116 for SC, and 165 for VI. From these estimates, 661–758 breeding pairs are present range-wide: 352–374 in Canada and 309–384 in the United States. The recovery team and Recovery Implementation Groups (RIGs) will refine estimates of population abundance in B.C. using advanced techniques for modelling habitat and population levels as outlined in the critical habitat section. This work will contribute toward critical habitat delineation, which will be presented in an action plan.

The most imminent threats to populations of *A. gentilis laingi* within B.C. are related to the loss and fragmentation of nesting and foraging habitat, and subsequent reductions in prey diversity and availability. As well, increased forest fragmentation leads to more open habitats and a subsequent increase in edge-dwelling species. This may result in greater depredation of adults, young, and eggs, and competition for nests sites. Within the HG Conservation Region, introduced species threaten *A. gentilis laingi* but are also a source of prey. Consequently, the overall effect of introduced species within this conservation region is unclear. Currently, the level of each threat within conservation regions is not well understood and more work will be necessary to evaluate these perceived threats.

Notwithstanding these threats, the recovery team considers the recovery of *A. gentilis laingi* to be biologically and technically feasible throughout its B.C. range. The recovery team based this assessment on the estimated size of the current breeding population, evidence of successful breeding throughout the species' B.C. range, and the ability to mitigate perceived threats and to recruit suitable habitat where necessary. The recovery team anticipates that there will be trade-offs between maintaining a sufficient amount of habitat for survival and recovery of populations of *A. gentilis laingi* and continuing to manage forests at current allowable annual cut levels and rotation periods within coastal B.C.

The long-term goal of this recovery strategy is to ensure that viable populations of *A. gentilis laingi* persist in each conservation region in coastal B.C. The recovery objectives are to (1) manage and, where necessary, conserve and recover habitat that meets the needs of *A. gentilis laingi* through its annual cycle; and (2) conserve and, where necessary, recover a well-distributed

and viable population of *A. gentilis laingi* within coastal B.C. These objectives are broad at this time because the recovery team lacks basic information on the amount of suitable habitat available historically, relative to current supply and predicted future supplies (under different management scenarios), as well as population responses to habitat supply over time. Therefore, the recovery team has outlined a number of activities in the critical habitat section that will help close these information gaps, refine population and habitat objectives, and delineate critical habitat for *A. gentilis laingi*.

Current recovery actions already underway include habitat suitability models that are being developed and verified by the Habitat Recovery Implementation Group (RIG) to determine habitat supply and distribution within the four Canadian conservation regions. Once habitat suitability is mapped, the RIG will use a territory model to predict how many pairs could potentially be supported within each conservation region. Habitat and territory models can be overlaid with a population model to estimate viable population size for each conservation region. The recovery team will use this information to set measurable population and distribution objectives, and to delineate habitat for the survival and recovery of populations within each conservation region.

Critical habitat will be defined within an action plan which will be completed within 2 years after approval of this recovery strategy. Ongoing and new inventory and monitoring programs enable the recovery team to evaluate breeding populations. Stewardship and outreach will be important components to the success of implementing this recovery strategy and subsequent action plan recommendations.

Terms in boldface type appear in the glossary at the end of this document. As well, unpublished reports cited within this document are available, where possible, at the Ministry of Forests website: <<http://www.for.gov.bc.ca/hfd/library/index.htm>>. Data statistics are reported as means $\pm$ standard errors, unless otherwise specified.

TABLE OF CONTENTS

RECOVERY TEAM MEMBERS.....	iv
AUTHORS.....	vi
RESPONSIBLE JURISDICTIONS	vi
ACKNOWLEDGEMENTS	vi
EXECUTIVE SUMMARY	vii
BACKGROUND	1
Status Rankings.....	1
Species assessment information from COSEWIC	1
B.C. Conservation Data Centre	1
United States	1
Description of the Species	1
Identification characteristics	1
Taxonomic position.....	2
Distribution	3
Global	3
Canadian	6
Porportion of global distribution in canada	6
Distribution trend	6
Population Abundance.....	7
Global	7
Percent of global abundance in canada	7
Population trends.....	8
Habitat Needs of the Northern Goshawk.....	8
Nesting habitat.....	9
Foraging habitat.....	10
Winter habitat	11
Dispersal Habitat	11
Roosting habitat.....	11
Habitat trends	11
Biological Limiting Factors	12
Reproduction	12
Survivorship.....	13
Mortality	14
Recruitment and dispersal.....	14
Hunting behaviour and prey availability.....	15
Competition	15
Ecological Role	16
Importance to People.....	16
Known and Perceived Threats.....	16
Nesting and foraging habitat loss and fragmentation.....	17
Prey diversity and availability	18
Genetic isolation.....	18
Introduced species	19
Depredation and competition	19
Climate change.....	20
Human disturbance	20
Disease.....	21
Actions Already Completed or Underway	21
Knowledge Gaps	22
Habitat availability and requirements	22
Diet and prey availability	22
Population abundance and demographic parameters	23
Population genetics and distribution.....	23

Miscellaneous.....	23
RECOVERY	23
Recovery Feasibility.....	23
Recovery Goal	25
Recovery Objectives.....	25
Approaches Recommended to Meet Recovery Objectives.....	26
Recovery Planning Table	26
Performance Measures	31
Critical Habitat.....	31
Identification of the species' critical habitat	31
Recommended schedule of studies to identify critical habitat	31
Existing and Recommended Approaches to Habitat Protection.....	32
Effects on Other Species	32
Socioeconomic Considerations	32
Anticipated Conflicts	33
Recommended Approach for Recovery Implementation.....	33
Statement on Action Plans	34
REFERENCES.....	35
Glossary	49
Appendix 1	52

LIST OF TABLES

Table 1. Estimated number of breeding pairs of <i>A. gentilis laingi</i> within each conservation region.....	8
Table 2. Identification and ranking (0 = no threat; 1 = low; 2 = moderate; 3 = high) of threats posed to <i>A. gentilis laingi</i> within each B.C. conservation region.....	16
Table 3. Broad strategies that will be used to address threats and to achieve recovery of habitat and populations for <i>A. gentilis laingi</i>	26
Table 4. Steps necessary to establish measurable and science-based habitat and population objectives and to delineate critical habitat for <i>A. gentilis laingi</i> within each conservation region in B.C.	31

LIST OF FIGURES

Figure 1. Range map for Northern Goshawk <i>Accipiter gentilis laingi</i>	5
Figure 2. Graphical representation of the hierarchical components within home ranges of Northern Goshawks.....	9

BACKGROUND

Status Rankings

Species assessment information from COSEWIC

Common Name: Northern Goshawk, *laingi* subspecies
Scientific Name: *Accipiter gentilis laingi*
Status: Threatened
Reason for Designation: This small, **sedentary**¹ goshawk population has been negatively impacted by degradation of forested habitat.
Last Examination and Change: November 2000 up-listed from Special Concern to Threatened
Canadian Occurrence: British Columbia
Status History: Designated Special Concern in April 1995. Status re-examined and designated Threatened in November 2000. Last assessment based on an updated status report.

B.C. Conservation Data Centre

The Northern Goshawk, *laingi* subspecies, is ranked a globally (T2) and provincially imperilled subspecies (S2B; Natureserve 2007; B.C. Conservation Data Centre 2005).

United States

The status of *A. gentilis laingi* in southeast Alaska has had an extensive litigation history in U.S. courts beginning in 1994 and this debate is ongoing (Squires and Kennedy 2006; S. Brockman, pers. comm.). Currently, the Alaska Department of Fish and Game consider *A. gentilis laingi* as a species of Special Concern and the U.S. Fish and Wildlife Service (USFWS) consider *A. gentilis laingi* to be a Sensitive species in southeast Alaska (<http://wildlife.alaska.gov/index.cfm?adfg=concern.goshawk>). The Washington Department of Fish and Wildlife (WDF&W) only recognizes *A. gentilis atricapillus* to occur in Washington (Desimone and Hays 2004), although several researchers believe *A. gentilis laingi* reside in the coastal forests of western Washington (S. Finn, pers. comm.; S. Desimone, pers. comm.). The WDF&W consider Northern Goshawks² in Washington to be a State Candidate species because of concerns about its population status (Desimone and Hays 2004).

Description of the Species

Identification characteristics

Northern Goshawks are raven-sized (55–61 cm in length; Squires and Reynolds 1997) raptors with short, rounded wings and long tails; males are smaller than females. Although individuals

¹ **Terms in boldface type** appear in the glossary at the end of this document.

² “Northern Goshawk” within this document refers generically to both subspecies (*A. gentilis laingi* and *A. gentilis atricapillus*), unless the subspecies is specified.

may become sexually mature within their first year (Squires and Reynolds 1997), plumage characteristics differ between birds <3 years old (immatures) and ≥3 years old (adults). Adults have a conspicuous white eye-stripe that separates their black crown from their blue-grey back. Their chests are white with dense grey barring that appears light grey from a distance; their tails have bands of alternating grey and black. Adult eye-colour varies from orange to dark red, and generally becomes darker with age. Immatures have a faint white eye-stripe and are overall brown with chests that are buff-coloured with dark brown vertical streaks. Immature Northern Goshawks start with a blue-grey eye colour that turns yellow in their first year. These descriptions are based on those outlined by Squires and Reynolds (1997), National Geographic Society (1999), and Sibley (2000). Intermediate plumages between immature and adults are described by Bond and Stabler (1941) and Squires and Reynolds (1997). Goshawks can be aged from plumage characteristics until they are 3 years old; individuals ≥3 years have similar feather colouration and patterns (Bond and Stabler 1941).

Northern Goshawks may also be distinguished from most other raptors by their flight pattern of flap-flap-flap-glide and direct powerful flight within forests (Dunne *et al.* 1988), although other *Accipiter* species (*A. cooperii*, *A. striatus*) have similar flight patterns.

Taxonomic position

Two **subspecies** of Northern Goshawks are recognized in British Columbia based on morphological distinctions: *Accipiter gentilis atricapillus* and *A. gentilis laingi* (AOU 1957, 1983; Palmer 1988; COSEWIC 2000). The subspecies *A. gentilis laingi* was described from a type-specimen collected on Haida Gwaii/Queen Charlotte Islands (hereafter Haida Gwaii) by Taverner (1940) and was therefore formerly referred to as the Queen Charlotte Goshawk. Originally, *A. gentilis laingi* was considered a unique subspecies because adults and immatures had darker plumage than *A. gentilis atricapillus* (Taverner 1940). Later, *A. gentilis laingi* was also recognized to be smaller (Johnson 1989; Whaley and White 1994; Flatten and McClaren, in prep.). *Accipiter gentilis laingi* likely hybridizes with *A. gentilis atricapillus* along the range boundary between these two subspecies.

The ecological significance of the darker plumage and smaller size of *A. gentilis laingi* may be an adaptation to inhabiting the darker, denser coastal forests. Within coastal **habitats**, darker plumage may increase camouflage and enhance thermoregulation, and a smaller size may improve manoeuvrability. Compared with the interior subspecies of Northern Goshawk, *A. gentilis laingi* appears to consume more and smaller avian prey, and their smaller size may aid in the capture of such prey (Whaley and White 1994; Watson *et al.* 1998; Ethier 1999; Lewis *et al.* 2006).

Early genetic analyses of Northern Goshawks throughout North America detected little genetic variation throughout their range (Gavin and May 1996). However, early genetic techniques are now considered to be inappropriate for delineating subspecific differences (Andersen *et al.* 2003). Additionally, no genetic samples from Haida Gwaii or Vancouver Island were included in early analyses. More advanced genetic techniques are currently being conducted by the U.S. Geological Survey in Anchorage, Alaska (Sonsthagen *et al.* 2004; Talbot *et al.* 2005; S. Talbot, pers. comm.) and by UC Davis, California (Bayard de Volo *et al.* 2005; R.T. Reynolds, pers.

comm.). These analyses include samples of blood, eggshells, and feathers collected by researchers from areas within the range of *A. gentilis laingi* (Vancouver Island, Haida Gwaii, southeast Alaska, and the mainland coast of B.C.) and areas along the range boundary (interior Alaska and interior B.C.). Recent genetic analyses suggest that coastal populations of Northern Goshawks may not be **panmictic**, especially individuals from Haida Gwaii, which may be genetically isolated from adjacent populations (Talbot 2006). Preliminary results from mtDNA suggest that populations in Haida Gwaii have two unique haplotypes and may have been isolated for >9,000 years (Talbot 2006).

To understand the genetic relationship among coastal populations, S. Talbot is conducting more detailed genetic analyses. To date, microsatellite DNA analyses suggest that Vancouver Island and coastal mainland B.C. populations are interbreeding. However, Vancouver Island and coastal mainland B.C. populations appear not to be interbreeding with interior B.C. populations. Although the recovery team requires more genetic samples from coastal mainland B.C., especially along the range boundary, it recognizes that an intergradation zone is likely along the range boundary of the subspecies where genetic delineations will be less clear.

Although the recovery team is not yet able to interpret the significance of Talbot's (2006) genetic analyses with respect to the status and distribution of *A. gentilis laingi*, it will consider these results to inform recovery actions within different conservation regions.

Distribution

Global distribution

Accipiter gentilis laingi occurs within the Pacific Northwest coast of the United States and Canada (Figure 1). In the United States, *A. gentilis laingi* occurs within coastal areas of southeast Alaska and Washington and possibly, Oregon and California (Jewett *et al.* 1953; Beebe 1974; Flatten and McClaren, in prep.). In southeast Alaska, the core range for *A. gentilis laingi* occurs from Dixon Entrance, through the coastal mainland and islands of the Alexander Archipelago, north to Icy Strait and Lynn Canal (Iverson *et al.* 1996); a small portion of the range may also occur north of Yakutat Bay. The recovery team produced a map that reflects the best available information on the potential range of *A. gentilis laingi* using a combination of morphometric data, radio-telemetry data, and base mapping that reflected coastal habitat and prey types for this subspecies (Figure 1). Within this range map the recovery team identified a zone where coastal habitat types transition to interior habitat types, which reflects an area where differences between *A. gentilis laingi* and *A. gentilis atricapillus* are likely less clear. *Accipiter gentilis laingi* may occur within coastal Oregon and California but, until better information becomes available, these areas are not considered to be part of the range of *A. gentilis laingi*. Habitat base mapping data were extracted from ecoregional mapping from the Shining Mountains Project database³ and biogeoclimatic ecosystem classification mapping for British Columbia (MacKinnon *et al.* 1992). The recovery team used base thematic mapper satellite imagery from B.C. and coverage produced by the WDF&W⁴ to map the extent of urbanization and agriculture to reflect potential permanent range loss for *A. gentilis laingi*. Although there is currently no evidence of breeding

³ <<http://srmwww.gov.bc.ca/ecology/bei/shiningmntns.html>>

⁴ <<http://wdfw.wa.gov/wlm/gap/landcov.htm>>

by *A. gentilis laingi* within the urban/agricultural zone on the range map (see Rutz *et al.* 2006), the recovery team acknowledges that scattered pairs may breed within the area it is considering to be historic.

To mitigate threats and implement recovery actions, the recovery team identified six conservation regions within the global range of *A. gentilis laingi*: (1) southeast Alaska (SEAK); (2) Haida Gwaii (HG); (3) North Coast, B.C. (NC); (4) South Coast, B.C. (SC); (5) Vancouver Island (VI); and (6) Western Washington (WA) (Figure 1). The recovery team chose these conservation regions because they reflect differences in habitat types, prey species composition, and land use pressures, and therefore have unique threats (see Table 2).

Because this is a Canadian recovery strategy, only those conservation regions within Canada (HG, NC, SC, and VI) will be addressed in this strategy. However, this strategy was developed based on data collected within the United States and Canada.

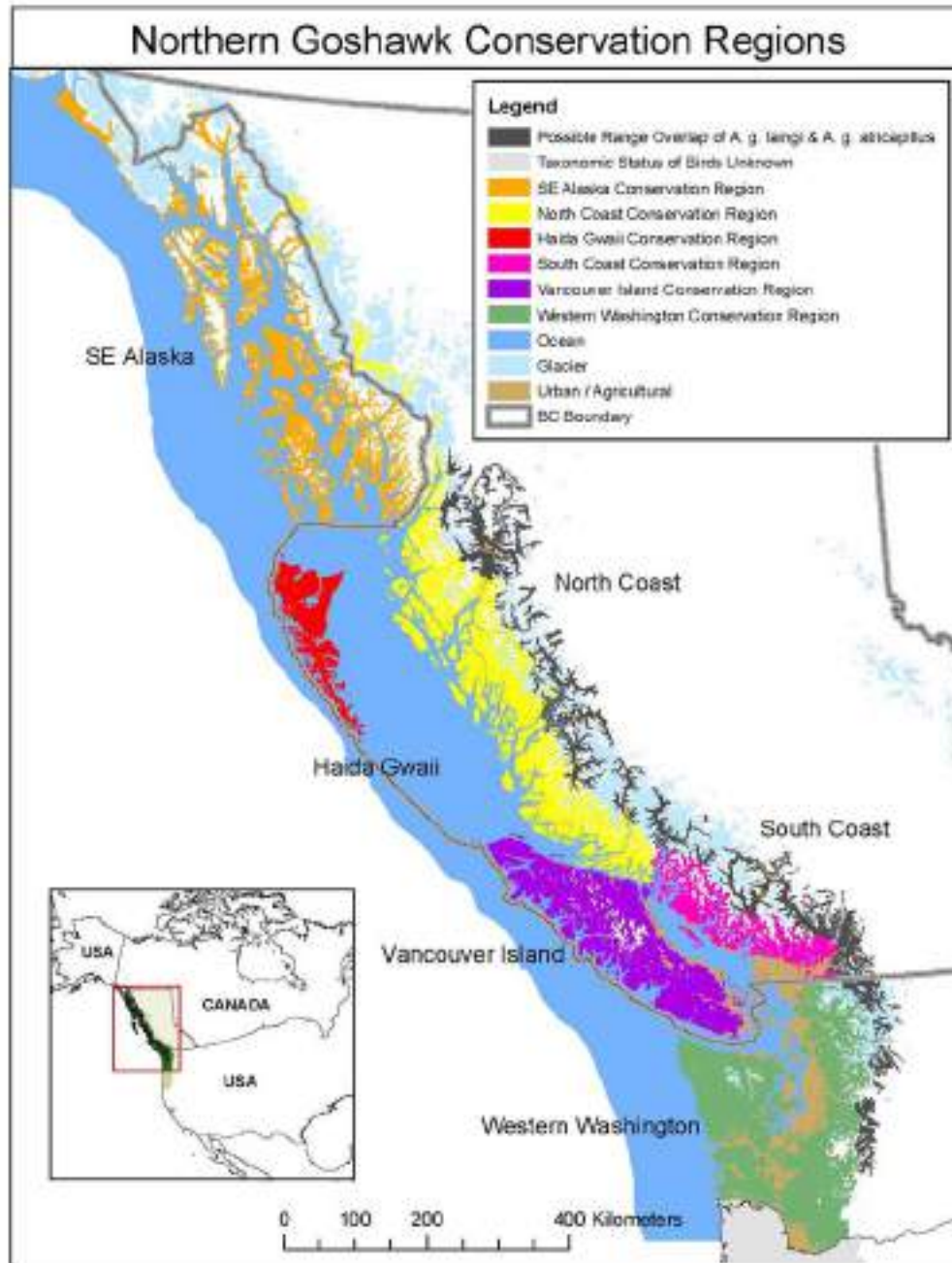


Figure 1. Range map for Northern Goshawk, *Accipiter gentilis laingi*. The British Columbia portion of the range of *A. gentilis laingi* reflects the distribution of wet Coastal Western Hemlock (CWH) biogeoclimatic subzones/variants and the Coastal Douglas-fir (CDF) biogeoclimatic zone. The recovery team has identified a zone (the drier variants of CWH on the coastal mainland) where *A. gentilis laingi* and *A. gentilis atricapillus* likely overlap. The recovery team used urbanization and agriculture as the best way to approximate the portions of the range of *A. gentilis laingi* that have been permanently lost, although the recovery team recognizes scattered pairs may be breeding within these areas. Four conservation regions (Haida Gwaii, North Coast, South Coast, and Vancouver Island) occur within Canadian jurisdiction (British Columbia) and two occur within U.S. jurisdiction (Western Washington and SE Alaska). The taxonomic status of individuals within coastal Oregon and California remains unknown. This recovery strategy will only address the Canadian portion of the range of *A. gentilis laingi*.

Canadian distribution

Within Canada, 100% of the range of *A. gentilis laingi* occurs within B.C. (Figure 1). Within B.C., this subspecies inhabits Haida Gwaii, Vancouver Island, the coastal islands, and the coastal mainland west of the Coast Mountains (AOU 1983; Campbell *et al.* 1990b; COSEWIC 2000; McClaren 2003). Within B.C., the range of *A. gentilis laingi* is divided among four conservation regions such that approximately 47% of current range (all of which may not be suitable habitat) is within the NC Conservation Region, 17% within the SC Conservation Region, 27% within the VI Conservation Region, and 9% within the HG conservation region. Until further information is available, the recovery team assumes the Canadian range of this subspecies follows the distribution of the Coastal Western Hemlock (CWH) and Coastal Douglas-fir (CDF) **biogeoclimatic subzones/variants** (Green and Klinka 1994). Within the NC and SC Conservation Regions, glaciated regions of the Coast Mountain Range likely form a divide between *A. gentilis laingi* and *A. gentilis atricapillus* populations. However, in less glaciated areas, drier CWH subzones link coastal forests to interior forests. The recovery team considers these drier CWH subzones/variants (CWHds1, CWHds2, CWHms1, CWHms2, CWHws1, CWHws2) to be transitional between subspecies. This transitional area accounts for 18% of the total B.C. range. A lack of substantial populations of Snowshoe Hare (*Lepus americanus*) within the CWH biogeoclimatic zone (Nagorsen 2005) suggests these forests may be less suitable for *A. gentilis atricapillus*. Using spatial data layers discussed in the “Global distribution” section, the recovery team calculated that about 3% of the B.C. range of *A. gentilis laingi* has been lost to urbanization and agriculture.

Proportion of distribution in Canada

Range boundaries for *A. gentilis laingi* are imprecise; therefore the exact percentage of the global population distribution within Canada is unknown. Using the *A. gentilis laingi* range map (Figure 1), it is estimated that approximately 50–60% of the total land mass occurs within Canada and 100% of Canada’s distribution of this subspecies is within B.C.

Distribution trend

Historic and current changes in the distribution of *A. gentilis laingi* are unknown. Although small amounts (ca. 5%) of the range of this subspecies has been permanently lost from clearing forest lands for urbanization and agriculture along the southeast coast of Vancouver Island, lower mainland B.C. and Seattle, WA, there is little evidence to suggest this habitat loss has resulted in major range contractions. Nevertheless, the distribution patterns of Northern Goshawks in North America have likely been influenced over the past century by harvesting of mature and old forests, reduced rotation periods between harvests (second and third pass relative to first pass), and changes in distributions and composition of prey species (e.g., introduced species) (DeStefano 1998; Andersen *et al.* 2003; Kennedy 2003).

Population Abundance

Global abundance

Current and historic estimates of population abundance for *A. gentilis laingi* are imprecise because it is very difficult to estimate their survival and recruitment. Therefore, estimates of population abundance have been inferred from the number of pairs that a given amount of suitable habitat could support, breeding densities, as well as habitat suitability and supply modelling. Habitat suitability modelling has not been completed for VI, WA, and SEAK conservation regions, and therefore population estimates for these conservation regions are less certain than those for HG, SC, and NC conservation regions. The recovery team estimated the range of breeding pairs within each conservation region using the estimated number of **territories**, breeding densities, and measured annual occupancy rates (Table 1; see “Population trends” section). It is important to integrate occupancy rates and estimated number of pairs because not all **nest areas** are occupied annually by breeding pairs and research suggests that individuals, especially adult females, may use more than one nest area to breed over successive years (Iverson *et al.* 1996; McClaren 2003). This methodology assumes that breeding pairs are territorial and do not pack into available suitable habitat. Estimates of population abundance in B.C. will be refined with advanced techniques used to model habitat and populations (see “critical habitat” section).

COSEWIC’s designation of Threatened for *A. gentilis laingi* was based on an estimate of <1,000 mature individuals within Canada combined with imminent threats posed from degradation of forested habitat (COSEWIC assessment criterion D1; COSEWIC 2000). There is strong evidence to suggest that breeding densities of *A. gentilis laingi* are lower than those of *A. gentilis atricapillus* (Reynolds *et al.* 1994; Titus *et al.* 1994; Woodbridge and Detrich 1994; Doyle 2003a; McClaren 2003). Non-breeding individuals may play an important role in buffering populations of *A. gentilis laingi* from decline (Newton 1991; Iverson *et al.* 1996; Hunt 1998). In Finland, Lindén and Wikman (1983) estimated 35–52% of a population of European Goshawks (*A. gentilis gentilis*) to be non-breeders. Non-breeding floaters within populations play an important role to fill vacancies in nest areas when breeding individuals die; during periods of high prey availability, more individuals are available to occupy nest areas and produce young (Doyle and Smith 1994).

Until further genetic work suggests otherwise, the recovery team will assume that coastal populations of *A. gentilis laingi* are panmictic, except for individuals from Haida Gwaii, which may be genetically isolated from adjacent populations (Talbot *et al.* 2005; Talbot 2006).

Percentage of global abundance in Canada

Estimates of population abundance for *A. gentilis laingi* are imprecise. Based on the best available population estimates provided in Table 1 and the following population trends section, approximately 50% of the global population of *A. gentilis laingi* resides within Canada.

Population trends

Estimates of population trends are uncertain for *A. gentilis laingi* because nest areas are difficult to monitor (low detection rates, high annual variability in occupancy, large distance between alternative nests) and survivorship data are lacking from several conservation regions (Doyle 2003a; McClaren 2003; McClaren *et al.* 2003).

Table 1. Estimated number of breeding pairs of *A. gentilis laingi* within each conservation region.

Country	Conservation region	Estimated # of potential territories	Territory occupancy rates	Territory spacing $\bar{x} \pm se$ (range)	Estimated # of breeding pairs
Canada	Haida Gwaii	24–43 ^a	43% ^b	10.8 $\pm$ 0.6 km ^c	10–18
Canada	North Coast, B.C.	130–136	unknown, applied VI's 55% ^d	unknown, used HG's estimate of 10.8 km	71–75
Canada	South Coast, B.C.	193–210	unknown, applied VI's 55%	unknown, used VI's estimate of 6.9 km	106 - 116
Canada	Vancouver Island	300 ^e	55%	6.9 $\pm$ 0.7 km ^f	165
TOTAL	CANADA				352–374
USA	Southeast Alaska	580–747 ^g	45% ^h	10.5 (7–15.2) ⁱ	261–336
USA	Washington	120 ^j	40% ^k	unknown	48
TOTAL	UNITED STATES				309–384
TOTAL	RANGE WIDE				661–758

Note: The number of potential territories modelled for HG, NC, and SC conservation regions was based on a medium habitat threshold of >40% moderate and high foraging habitat suitability within territories (Mahon *et al.* 2007; Smith *et al.* 2007).

^a Holt (2004); ^b Doyle (2005); ^c Doyle (2003a); ^d McClaren (2003) ^e COSEWIC (2000); ^f McClaren (2003); ^g USFWS (2007); ^h Flatten *et al.* (2001); ⁱ Iverson *et al.* (1996); ^j S. Finn, pers. comm., 2005; T. Bloxton, pers. comm., 2005 ^k Finn *et al.* (2002).

Habitat Needs of the Northern Goshawk

Home ranges of breeding Northern Goshawks are described as a hierarchical arrangement of biological components including the nest area (nest trees), **post-fledging (family) area** (PFA), and **foraging area** (Reynolds *et al.* 1992; Kennedy *et al.* 1994; McClaren *et al.* 2005; Figure 2). Threats to these habitat components should be mitigated simultaneously, because all components

are necessary to ensure successful breeding and survival, and to facilitate dispersal of juvenile Northern Goshawks. See the “Critical habitat” section for action plan.

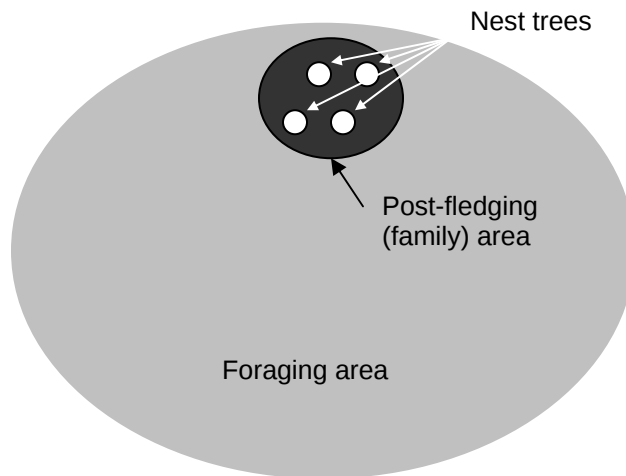


Figure 2. Graphical representation of the hierarchical components within home ranges of Northern Goshawks (revised from Reynolds *et al.* 1992). The location of nest trees and post-fledging areas are not necessarily centred within foraging areas.

Nesting habitat

Nest areas function to provide multiple nest trees, roost trees, and prey plucking posts, and they act as centres for courtship behaviours and fledgling movements during the post-fledging period (Reynolds *et al.* 1992). PFAs surround and include active nest trees and may correspond to the **core-use areas** of adult females and the area young birds use before they become independent of adults and leave their natal areas (Kennedy *et al.* 1994). The spacing pattern of alternative nest trees within home ranges, coupled with information from radio-telemetry of fledglings from 12 nests on Vancouver Island, suggests the size of the PFA for *A. gentilis laingi* is about 100–200 ha (McClaren *et al.* 2005). Because the biological role of post-fledging areas and nest areas appear to be functionally similar (McClaren *et al.* 2005), these areas will be considered as one in this document.

In general, *A. gentilis laingi* select nesting habitat based on stand structure rather than on stand age and species composition per se. Universal characteristics of nest stands of Northern Goshawks throughout North America include mature and old forests, closed canopies ($\geq 50\%$), and relatively large diameter trees (Iverson *et al.* 1996; Squires and Reynolds 1997; Daw *et al.* 1998; Ethier 1999; Andersen *et al.* 2003; Kennedy 2003; Greenwald *et al.* 2005). Goshawks select nest trees with structural attributes that will support their relatively large stick nests (ca. 1-m diameter; E. McClaren, unpublished data) and these often include trees with deformities and sometimes snags. Within VI and SC conservation regions, forests may reach these characteristics on productive growing sites at >50–60 years whereas within NC and HG conservation regions, forests do not obtain these characteristics until >80–100 years (McClaren 2003; Doyle 2006). At

a larger scale, *A. gentilis laingi* typically nest >200 m from **hard edges** and in stands that are >100 ha (Ethier 1999; McClaren and Pendergast 2003). *Accipiter gentilis laingi* nest at elevations between 0 and 900 m, on moderate slopes (<50%) and typically within the mid- to lower mesoslope position (McClaren 2003; Doyle 2005). Suitable biogeoclimatic zones for breeding throughout the range of *A. gentilis laingi* include the Coastal Western Hemlock and Coastal Douglas-fir biogeoclimatic zones (McClaren 2003). Maritime variants of the Coastal Western Hemlock zone constitute the core part of the range of *A. gentilis laingi*, whereas subarctic variants form the transitional zone where both subspecies likely occur.

Foraging habitat

Foraging areas make up the majority of Northern Goshawk breeding home ranges; within these areas, adults and dispersing immatures hunt. Foraging areas may include nest trees and PFAs. As well, individuals within a pair may have entirely different foraging areas from each other (Boal *et al.* 2003) and they may change their foraging areas among seasons and years (Titus *et al.* 1994; McClaren 2003). Foraging areas vary in size among localities and among individuals according to experience, hunting efficiency, food requirements (brood size), and the availability of food within home ranges (Kennedy *et al.* 1994).

Few studies have estimated the size of foraging areas for *A. gentilis laingi* because limited information is available on foraging activities. Most often, the size of the foraging area is based on the estimated home range size, with the assumption that individuals forage widely throughout their home range. However, Bloxton (2002) reported that *A. gentilis laingi* on the Olympic Peninsula, Washington, concentrated foraging activities within 5 km of active nests and within only 15% of their entire breeding home range. On the Olympic Peninsula, average breeding season home range size for males and females (breeders and non-breeders combined) was 3710 ± 688 ha ($n = 14$; range: 844–8676 ha; Bloxton 2002). In southeast Alaska, median breeding home ranges for *A. gentilis laingi* were 4,300 ha ($n = 16$) for females and 4,600 ha ($n = 20$) for males (S. Lewis, unpublished data). It is important to consider foraging habitat for both members of a pair because Boal *et al.* (2003) reported that breeding home ranges of 10 pairs of *A. gentilis atricapillus* in Minnesota overlapped $\leq 50\%$ within pairs. Home ranges of *A. gentilis laingi* appear to be larger than for *A. gentilis atricapillus* likely because prey densities are lower throughout coastal forests (Crocker-Bedford 1994; Titus *et al.* 1994; USFWS 1997; Boal *et al.* 2003).

In general, it is more difficult to discern unique patterns of habitat selection by Northern Goshawks at larger scales and as the landscape context around nests becomes more varied (Iverson *et al.* 1996; Ethier 1999; Daw and DeStefano 2001; Finn *et al.* 2002; McClaren and Pendergast 2003; McGrath *et al.* 2003). Within B.C., there is a lack of information on the amount and juxtaposition of foraging habitat required by a breeding pair to support successful reproduction. However, most studies suggest somewhere between 40 and 60% of suitable foraging habitat within home ranges of Northern Goshawks will support a pair over time (Reynolds *et al.* 1992; Patla 1997; Finn *et al.* 2002; Doyle 2005). Northern Goshawks are morphologically and behaviourally adapted for using the flight space between forest canopies and understorey vegetation (see the “Hunting behaviour and prey availability” section). Therefore, foraging habitats are similar to nesting habitats and are characterized by closed

canopies, relatively large diameter trees, and open understoreys (Beier and Drennan 1997; Bloxton 2002; Drennan and Beier 2003; Boal *et al.* 2005) — attributes that provide for flight space and access to prey. Radio-telemetry data suggest that Northern Goshawks also forage in areas where they do not nest, including forest edges, riparian areas, estuaries, and elevations >900 m (Iverson *et al.* 1996; Bloxton 2002; McClaren 2003; Squires and Kennedy 2006).

Winter habitat

Foraging habitat attributes for *A. gentilis laingi* in the winter are poorly understood. In southeast Alaska, *A. gentilis laingi* expanded its breeding home ranges during winter to a median size of 14,700 ha ($n = 18$) for females and 13,400 ($n = 14$) for males (S. Lewis, unpublished data). Radio- and satellite-telemetry work on Vancouver Island and in southeast Alaska suggests foraging habitat characteristics for *A. gentilis laingi* in winter are similar to the breeding season, although some individuals may use subalpine forests to follow altitudinal gradients in prey, and use shoreline habitats (Iverson *et al.* 1996; McClaren 2003). It is unknown whether winter habitat for juvenile Northern Goshawks differs from adults.

Dispersal habitat

Habitat characteristics that facilitate successful dispersal for *A. gentilis laingi* are unknown. The recovery team assumes these characteristics are similar to foraging habitat characteristics because some studies suggest immature *A. gentilis atricapillus* are more vulnerable to depredation and starvation in areas with low canopy closure and low prey abundance and availability (Wiens *et al.* 2006). The spatial configuration between dispersal habitat of Northern Goshawks and where individuals first breed is unknown, but it is reasonable to assume that large distances between suitable breeding areas will reduce successful dispersal.

Roosting habitat

Little information is available for the habitat characteristics of roost sites for *A. gentilis laingi*. A recent study on *A. gentilis atricapillus* in California reported roost trees to be in stands that had similar canopy closure and tree diameter to nests but had higher tree densities than nest stands (Rickman *et al.* 2005). Roost trees were also smaller in diameter and lower in height than nest trees (Rickman *et al.* 2005).

Habitat trends

Relative to the abundance of mature and old-growth forests that existed before industrialized forest harvesting, there has been a reduction in the amount of habitat for *A. gentilis laingi* (COSEWIC 2000; Doyle 2003a; Holt 2004; Smith *et al.* 2007). It is unclear whether the overall balance of suitable habitat for *A. gentilis laingi* will be stable, positive, or negative in future years as second-growth forests mature and become suitable habitat for this subspecies. However, many of these forests are also becoming commercially viable for harvesting. Current and predicted future amounts of suitable habitat throughout the Canadian range of *A. gentilis laingi*, relative to historic amounts, will be calculated and reported in an action plan (see the critical habitat section). Within southeast Alaska, approximately 15% of productive old-growth forests on national forest and private lands were harvested as of 1995 and second-growth forests are not

yet structurally suitable for nesting (Iverson *et al.* 1996). Coastal forests in Washington have had similar harvesting pressures as VI and SC conservation regions (Finn *et al.* 2002).

Biological Limiting Factors

Reproduction

Population trends and population estimates for goshawks are unclear and, as in many other species this is because the biological limiting factors are likely a combination of several biological traits including relatively low reproductive rates, low first year survival, late breeding age and relatively few reproductive years.

Most individuals initiate breeding at >2 years but some females breed at 1–2 years of age (Squires and Reynolds 1997; McClaren 2003). As the age of birds ≥ 3 years cannot be reliably determined (Bond and Stabler 1941), the exact age of most breeding birds captured is unknown. In a long-term study of known-age marked birds in Arizona, the average age that *A. gentilis atricapillus* were observed first breeding was 4.2 ± 0.3 years and 3.9 ± 0.3 years for females and males, respectively (Wiens *et al.* 2006). Northern Goshawks are **socially monogamous**, territorial, **non-colonial**, **synchronously breeding** raptors (Kennedy 2003). During the winter and into the courtship period, females must reach a critical body mass required for egg laying (Marcström and Kenward 1981; Newton *et al.* 1983). Therefore, prey availability in late winter and early spring influences the onset of breeding each year (Keane 1999). Females obtain nearly all food from mates during the pre-laying, incubation, and brooding periods (Duncan and Kirk 1994; Iverson *et al.* 1996). Cool, wet weather in the spring may cause egg-chilling and nestling mortality directly or it may indirectly cause nest failure by limiting foraging opportunities of males (Kostrzewa and Kostrzewa 1990; Penteriani 1997; Bloxton 2002). Average clutch size for *A. gentilis laingi* is unknown. The clutches of *A. gentilis atricapillus* in North America average 2.7 eggs with a range from 1 to 5 eggs (Squires and Reynolds 1997). Females lay only one clutch per breeding season (Squires and Reynolds 1997). Lifetime reproductive success for *A. gentilis laingi* is unknown but high turnover rates of adult females within nest areas on Vancouver Island (78.9%, $n = 57$) suggest it could be low (McClaren 2003). A long-term study on European Goshawks reported adult females to breed for a median of 2 years of their lifespan and produce a median of two nestlings over this time (Krüger 2005). Likewise, in Arizona, females and males spent an average of 2.18 ± 0.11 years and 1.96 ± 0.11 years, respectively, as breeders (Wiens and Reynolds 2005).

Mean nest productivity for *A. gentilis laingi* was 1.6 ± 0.1 fledglings per **active nest** ($n = 141$) for Vancouver Island from 1994 to 2002 (McClaren 2003), 1.5 ± 0.2 fledglings per active nest ($n = 15$) for Haida Gwaii from 1995 to 2004 (Chytyk and Dhanwant 1997; Doyle 2005), and 2.1 fledglings per active nest ($n = 87$) from 1991 to 1998 in southeast Alaska (Titus *et al.* 1999). Fledgling Northern Goshawks are fed by their parents for 35–55 days (McClaren *et al.* 2005) within nursery areas near nests called **post-fledging (family) areas (PFAs)** (Reynolds *et al.* 1992). The total time from egg laying until young initiate dispersal is between 100 and 127 days (Titus *et al.* 1994; Kennedy and Ward 2003; McClaren *et al.* 2005; Wiens *et al.* 2006).

Annual **occupancy rates** of nest areas for *A. gentilis laingi* are variable (HG: 43%, $n = 35$, Doyle 2005; WA: 40%, $n = 50$, Finn *et al.* 2002; SEAK: 45%, $n = 283$, Flatten *et al.* 2001; VI: 55%, $n = 163$, McClaren 2003), and generally, individual nest areas are occupied by breeding pairs once every 2–3 years. The actual occupancy rates are very difficult to determine because none of these estimates are adjusted for detection probability (MacKenzie *et al.* 2006), so the reported values likely represent minimum estimates. However, long-term monitoring of the same nest areas within each of these study areas has increased the probability of detecting birds earlier in the breeding season and has reduced the chance of detecting only successful breeders.

Breeding pairs space themselves regularly throughout suitable habitat, likely because of territoriality (McGowan 1975; Reynolds and Joy 1998; McClaren 2003; Reich *et al.* 2004; Doyle 2005). Breeding densities likely reflect prey availability and abundance (Newton 1979). Densities of *A. gentilis laingi* are low relative to those of *A. gentilis atricapillus* (Doyle and Smith 1994; Iverson *et al.* 1996; Doyle 2003b; McClaren 2003; Reich *et al.* 2004). Kennedy (1997) estimated the mean distance between adjacent breeding pairs for *A. gentilis atricapillus* to be from 3.0 to 5.6 km in North America whereas this distance is 6.9 ± 0.7 km ($n = 16$) between pairs of *A. gentilis laingi* on Vancouver Island (McClaren 2003) and is 11.3 ± 2.2 km (SD; $n = 6$) on Haida Gwaii (Doyle and McLennan 2003). These estimates need to be interpreted cautiously because they assume a census of the survey area and do not account for effective area surveyed (Roberson *et al.* 2005) or some other estimate of detection probability (MacKenzie *et al.* 2006).

Survivorship

Lifespan for *A. gentilis laingi* is unknown but the maximum lifespan reported for wild *A. gentilis atricapillus* is >15 years (R.T. Reynolds, pers. comm.). Mark-recapture analyses using radio-telemetry data from SEAK suggest mean annual survivorship of *A. gentilis laingi* adults (genders combined) to be 0.72 ($n = 39$; 95% CI: 0.56–0.88; Iverson *et al.* 1996), and 0.59 ± 0.10 ($n = 31$) for adult males only (K. Titus, unpublished data). Mean annual survival estimates reported for *A. gentilis atricapillus* (see review in Squires and Kennedy 2006) varies from 0.75 ± 0.02 in Arizona (Reynolds *et al.* 2004) and 0.86 ± 0.09 in New Mexico (Kennedy 1997) compared with 0.81 for *A. gentilis gentilis* (Kenward *et al.* 1999). Comparisons among subspecies are difficult because different studies employ different methods with different assumptions to calculate survivorship estimates. Although survival estimates after the first year do not exist for juvenile Northern Goshawks, mean survival for up to three months post-fledging for *A. gentilis atricapillus* hatched in Arizona was 0.71 ($n = 89$; 95% CI: 0.60–0.93; Wiens *et al.* 2006). In New Mexico and Utah, survival estimates ranged from 0.93 ± 0.06 (5.5 months post-fledging) to 0.56 ± 0.12 (3 months post-fledging; see review in Squires and Kennedy 2006). These studies suggest that food availability has the largest influence on fledgling survival during this time (Ward and Kennedy 1996; Dewey and Kennedy 2001; Wiens *et al.* 2006). Squires and Reynolds (1997) predict that survival of Northern Goshawks, like most raptors, is probably lowest during the first year of life. Sensitivity analyses of demographic parameters within population models for *A. gentilis laingi* suggest persistence of this subspecies would be sensitive to fluctuations in both adult and juvenile survivorship and to the proportion of females successfully nesting each year (Broberg 1997; USFWS 1997). Wiens *et al.* (2006) also suggested that populations of *A. gentilis atricapillus* are sensitive to juvenile survivorship because dispersing juveniles serve as an important mechanism for gene flow among populations.

Mortality

Populations of *A. gentilis laingi* experience the same general causes of mortality as other medium-sized raptors, including: starvation; depredation of adults, young, and eggs; **ectoparasites** and infectious diseases; prolonged periods of poor weather; competitive interactions; collisions; felling of active nest trees; and **persecution** (Marcström and Kenward 1981; Kostrzewa and Kostrzewa 1991; Patla 1997; Penteriani 1997; USFWS 1997; McClaren 2003). Individually, none of these factors are currently considered to threaten the subspecies. Pesticides and other contaminants, which were historically important causes of mortality, are no longer considered significant (Snyder *et al.* 1973; Havera and Duzan 1986; USFWS 1997; Cooper and Stevens 2000). Potentially new sources of mortality for *A. gentilis laingi* include epidemic disease from West Nile Virus (WNV) and other emerging diseases (see “Disease” under the “Threats” section). The degree to which each of the above mortality factors regulates *A. gentilis laingi* populations is unknown and probably varies by conservation region.

Recruitment and dispersal

Information on **recruitment** and **natal dispersal** in populations of Northern Goshawks is limited (USFWS 1997; Cooper and Stevens 2000; COSEWIC 2000; Squires and Kennedy 2006). No marked fledglings from VI ($n = 59$) or SEAK ($n = 86$) have joined their natal breeding populations (McClaren 2003; C. Flatten, unpublished data). Data from an 11-year study in Arizona suggest recruitment rates in *A. gentilis atricapillus* are very low (11%: 69 of 614 marked individuals; Wiens 2004).

Radio-tagged juvenile *A. gentilis laingi* were reported 11–162 km from natal sites on VI ($n = 2$; McClaren *et al.* 2005) and in SEAK ($n = 14$; Titus *et al.* 1994) during their first year. Distances between natal sites and breeding sites are unknown for this subspecies, although the median distance for *A. gentilis atricapillus* was 15 km (0.1–58.1 km) in Arizona (Reynolds *et al.* 2000; Wiens *et al.* 2006) and recoveries of dead birds up to 442 km from natal areas (Reynolds *et al.* 2000) suggest Northern Goshawks are capable of long-distance natal dispersal. However, water bodies between several populations of *A. gentilis laingi* may limit successful long-distance dispersal (e.g., nearest distance between HG and SEAK and between HG and NC Conservation Regions is 60 and 90 km, respectively).

Breeding dispersal of adult females appears to be more common in populations of *A. gentilis laingi* than in other subspecies and may result from poor-quality nesting areas or mates, the death or departure of a mate, low breeding densities, low annual productivity, or annual variation in food availability. For example, in SEAK, approximately 45% of radio-tagged adult females ($n = 19$) exhibited breeding dispersal compared with 5% for adult female *A. gentilis atricapillus* breeding in Northern Arizona (Reynolds and Joy 2006). Iverson *et al.* (1996) suggested that above-average site fidelity of males and higher breeding dispersal rates of female *A. gentilis laingi* in SEAK, compared to *A. gentilis atricapillus*, may reflect nest site scarcity for males and food stress for females. In general, both males and females exhibit site fidelity to nest areas, although pairs frequently use different nest trees within nest areas in consecutive breeding years. As long as sufficient nesting and foraging habitat exists within and near nest areas, *A. gentilis*

laingi pairs will continue to use nest areas over long periods (>10 years) (McClaren 2003; Doyle 2005).

Populations of *A. gentilis laingi* are characterized as non-migratory (Iverson *et al.* 1996; Bloxton 2002; McClaren 2003), although in some years adults may move from **breeding home ranges** to completely different **winter home ranges**; in other years adults will include their breeding home range within their winter home range (Iverson *et al.* 1996; McClaren 2003).

Hunting behaviour and prey availability

Northern Goshawk populations are described as being food-limited; prey availability and abundance are closely associated with landscape alterations, climate, and annual weather patterns (Squires and Reynolds 1997; McClaren *et al.* 2002; Keane *et al.* 2006; Reynolds *et al.* 2006). As well, food supply can indirectly be linked to competition for nest sites, siblicide rates, and depredation of adults or eggs (Estes *et al.* 1999; Dewey and Kennedy 2001).

Northern Goshawks possess morphological and behavioural adaptations for hunting within forested habitats (Squires and Reynolds 1997). Unlike Buteo hawks (e.g., Red-tailed Hawks, *Buteo jamaicensis*), Northern Goshawks generally do not soar in open habitats while hunting; they use a stop-and-go, short-stay perched-hunting pattern (Kenward 1982; Kennedy 2003), manoeuvring between trees below the forest canopy. Northern Goshawks are generalist predators of medium-sized birds and mammals (Squires and Reynolds 1997). Pronounced differences in body size between the sexes (males are smaller than females) may help mates to partition food resources and reduce competition. Prey caching may also assist individuals in meeting their energetic requirements during times of low prey availability or low hunting success (Schnell 1958; Lewis *et al.* 2006).

Populations of *A. gentilis laingi* inhabit islands and dense coastal forests with a low abundance and diversity of prey available compared with the drier, interior forest habitats occupied by *A. gentilis atricapillus* (Roberts 1997; Ethier 1999; Doyle 2003b; Lewis *et al.* 2006). Mammalian prey items comprise a lower proportion of the prey of *A. gentilis laingi* than *A. gentilis atricapillus* (Watson *et al.* 1998; Ethier 1999; Bloxton 2002; Andersen *et al.* 2003; Lewis *et al.* 2006). Nevertheless, Red Squirrels (*Tamiasciurus hudsonicus*) dominate breeding season diets of *A. gentilis laingi* (Roberts 1997; Ethier 1999; Doyle 2003b; Lewis *et al.* 2006). Introductions of prey species and land use activities may have altered prey composition and availability throughout the range of this subspecies. Such changes may not have been uniform across conservation regions (see prey diversity and availability under the threats section). Little information is available on the winter diet of *A. gentilis laingi*.

Competition

The degree to which *A. gentilis laingi* populations are limited by **intra-specific and inter-specific competition** for nest sites and for food is unknown.

Ecological Role

Accipiter gentilis laingi are a top avian predator within mature and old forests. As such, they likely play a complex ecological role and humans may never completely understand the mechanisms and associations of this role. However, it is known that *A. gentilis atricapillus* and *A. gentilis gentilis* can regulate prey populations, especially in areas where they select a few key prey species (Doyle and Smith 1994; Tornberg and Colpaert 2001; Kennedy 2003). Furthermore, *A. gentilis laingi* functions as a primary nest builder for other birds such as large forest owls (including Spotted Owls; Forsman and Giese 1997), Common Ravens (*Corvus corax*; E.L. McClaren, pers. observation 1998), and Great Blue Herons (*Ardea herodias*; F. Doyle, pers. observation 2000). As a large forest raptor, *A. gentilis laingi* likely influences the spacing and distribution of other forest raptors (Krüger 2002). Northern Goshawks are often considered to be an indicator of mature forest ecosystem health because they require the structural complexity of these forests to breed and forage.

Importance to People

Northern Goshawks are prized by birdwatchers and wildlife photographers because they are a rare sight and an impressive forest predator. They are also an important indicator of old and mature forest biodiversity, which is valued by many Canadians. *A. gentilis laingi* were a part of the St'aawaas Xaaydagaay (Haida Cumshewa ruling family name) culture and were referred to as the "Blue Hawk," likely a result of its blue-grey plumage (Barb Wilson, pers. comm. 2004). Northern Goshawks are sought by falconers for their aggressive nature and impressive flight and hunting skills (Squires and Reynolds 1997).

Known and Perceived Threats

The threats and rankings in Table 2 are based on the best available scientific information and, where data were unavailable, are based on expert opinion and data-derived estimates. Some threats within this table are interrelated but have been separated to focus recovery actions. Rankings within this table will need to be re-evaluated over time and additional threats may need to be added.

Table 2. Identification and ranking (0 = no threat; 1 = low; 2 = moderate; 3 = high) of threats posed to *A. gentilis laingi* within each B.C. conservation region.

Threat	Conservation region rankings			
	HG	NC	SC	VI
Habitat loss-nesting	2	1.5	2	2.5
Habitat loss-foraging	3	1.5	2	3
Habitat fragmentation	3	1.5	2	3
Prey diversity*	3	1	1	2
Prey availability	3	1.5	2	2.5
Genetic isolation*	3	0.5	0.5	0.5
Introduced species	2	0	0	0
Depredation of adults, eggs, and young	1	1	1	1
Competition for nest sites	1	1	1	1

Climate change*	1	1	1	1
Human disturbance	1	1	1	1
Disease*	1	1	1	1
Persecution	1	0	0.5	0.5

*The recovery team considers that it will have limited success at mitigating these threats.

Nesting and foraging habitat loss and fragmentation

Two major threats to populations of *A. gentilis laingi* are the conversion of mature and old-growth forest to young **seral stages** (i.e., **habitat loss**) and **habitat fragmentation**. Land use activities that create small, isolated patches of suitable habitat surrounded by young, dense, even-aged stands with few large diameter trees and reduced tree, shrub, and herb diversity may be detrimental to *A. gentilis laingi* and its prey populations (Iverson *et al.* 1996; Cooper and Stevens 2000; Krüger and Lindström 2001; Kennedy 2003). The consequences of the reduction in habitat quantity and quality discussed above include (1) reduced availability of nest sites; (2) reduced ability for immatures to disperse; (3) increased risk of depredation of adults, eggs, and young; (4) reduced gene flow among local populations; (5) reduced prey abundance and availability; (6) increased inter-specific competitive interactions with edge-adapted and open habitat species for prey and nest sites; (7) decreased survival and productivity; (8) decreased carrying capacity of landscapes for breeding pairs; (9) increased disturbance from humans; and (10) loss of suitable microclimate conditions at nest sites (Iverson *et al.* 1996; Squires and Reynolds 1997; COSEWIC 2000; Cooper and Stevens 2000; Kennedy 2003). The USFWS (1997) hypothesized that populations of *A. gentilis laingi* may be more energetically stressed than *A. gentilis atricapillus* because of lower prey densities throughout their range, and therefore, they may be more sensitive to reductions in habitat quality.

The primary cause of habitat loss and fragmentation for populations of *A. gentilis laingi* within productive coastal forests is large-scale forest harvesting. As well, harvest rotation periods (which in productive forests may be 50–80 years) coincide with forests developing suitable characteristics for *A. gentilis laingi*. Extensive forest harvesting in eastern North America and parts of Europe dramatically reduced populations of Northern and European Goshawks in the late 1800s (Petty 1989; Widén 1997; Kennedy 1997, 2003). In comparison, large-scale harvesting is much more recent in coastal B.C., and most harvesting before 1940 was small-scale and occurred near human settlements (Mackie 2000; Pearse 2001). Industrialized forestry was adopted between 1940 and 1980 within coastal B.C. and the allowable annual cut (AAC) steadily increased during this time, causing accessible, low elevation old-growth forests to be converted to younger forests through clearcutting (Marchak *et al.* 1999; Pearse 2001). Within the VI and SC conservation regions, second-growth forests are being recruited as habitat for *A. gentilis laingi*, especially within the drier and very productive biogeoclimatic variants (CDF, CWHxm1, CWHxm2), as these forests reach structural characteristics suitable for nesting and foraging (McClaren 2003; Marquis *et al.* 2005). Forests within the NC and HG conservation regions have a more recent harvest history and slower growing conditions, which will likely lengthen the time that second-growth forests will require to become suitable habitat for *A. gentilis laingi* (Doyle 2006).

Ultimately, the rate and extent at which habitat for *A. gentilis laingi* is removed relative to its recruitment, and the levels of protection of currently suitable habitat, will determine the severity

of this threat to populations. The level of threat is not merely a calculation of the balance between habitat loss and recruitment because Northern Goshawks have high fidelity to their breeding areas and so habitat loss within home ranges may have long-lasting effects on breeding pairs. The introduction of the Forest Practices Code of B.C. in 1995 shifted forest practices on Crown forest lands within coastal B.C. from progressive large-scale clearcutting to smaller (<40 ha) cutblocks with variable amounts of wildlife tree retention patches (B.C. Ministry of Forests 1995). As well, the increased use of helicopters as a harvest system for previously inaccessible stands has expanded the accessible timber harvesting landbase. Private forest lands within B.C. have not had to meet the same biodiversity objectives as Crown forest lands. Harvest pressures on private forest lands will pose the greatest threat to *A. gentilis laingi* within the VI conservation region, where 67% of the province's private forest lands exist and comprise approximately 3% of the managed forest landbase.⁵ As well, a lower diversity of mammalian prey on Vancouver Island and Haida Gwaii may mean that threats to foraging habitat are greater within these conservation regions.

To a lesser extent, urban development, windthrow (sometimes increased through harvest activities; Kramer *et al.* 2001; Penteriani *et al.* 2002), conversion of forests to agricultural lands, and forest insects and disease may also reduce the habitat quality for *A. gentilis laingi* (Squires and Reynolds 1997; Burleigh and Hodge 2004).

See Appendix 1 for an outline of existing approaches and measures available to protect *A. gentilis laingi* habitat in B.C.

Prey diversity and availability

The theory of island biogeography (MacArthur and Wilson 1967) suggests that species diversity will be lower on smaller than larger islands, and diversity will also be reduced as distances between mainland source populations and islands increases. It is therefore expected that VI and HG conservation regions should have a lower diversity of prey species for *A. gentilis laingi* than NC and SC conservation regions on mainland B.C. This is generally true as VI and HG conservation regions have lower avian and mammalian prey diversity than mainland conservation regions, and HG conservation region has even fewer species than VI conservation region (Campbell *et al.* 1990a, 1990b, 1990c, 1990d; Nagorsen 2002). This reduction in prey diversity may be a further threat to *A. gentilis laingi* populations on the islands, as any reduction in the annual abundance of any one prey may impact the ability of *A. gentilis laingi* to obtain enough food to meet their annual energetic requirements.

Genetic isolation

Genetic work by Talbot (2006) suggests that Vancouver Island and coastal mainland B.C. populations are interbreeding. However, Vancouver Island and coastal mainland B.C. populations appear not to be interbreeding with interior B.C. populations. Therefore, these populations have a small level of threat from genetic isolation. *Accipiter gentilis laingi* from Haida Gwaii have a very high risk of genetic isolation because genetic analyses suggest there is

⁵ <www.pmflc.ca>

very little gene flow among these individuals and other populations of *A. gentilis laingi* (Talbot 2006).

Introduced species

It is unlikely that **introduced species** within the VI, SC, and NC conservation regions have posed a threat to *A. gentilis laingi* populations. Instead, this subspecies may use some introduced species such as Eastern Cottontail Rabbits (*Sylvilagus floridanus*; Nagorsen 2002) as prey. However, within the HG conservation region, introduced species may substantially threaten *A. gentilis laingi*. Relevant introduced species include Sitka Black-tailed Deer (*Odocoileus hemionus sitkensis*), Red Squirrels, Raccoons (*Procyon lotor*), and rats (*Rattus* spp.). Black-tailed Deer, first introduced to Haida Gwaii in 1878 and then again in 1911 (Englestoft and Bland 2002), are likely having the greatest impact on prey populations of *A. gentilis laingi* because most of their prey occur within the ground-shrub zone (Reynolds and Meslow 1984) which the deer have over-browsed. With the exception of Black Bears (*Ursus americanus*), there are no predators to help regulate deer populations, resulting in an extremely high density of deer on Haida Gwaii (~30 deer/km²; Martin and Baltzinger 2002) compared with other conservation regions. Allombert *et al.* (2005a) showed that songbird abundance was 55–70% lower on islands with a >50-year history of deer browsing compared with islands without deer. Therefore, *A. gentilis laingi* may be indirectly impacted by deer overgrazing understory vegetation, which may reduce nest site availability and food supply for songbirds, which in turn may reduce populations of songbirds (Allombert *et al.* 2005b). Blue Grouse (*Dendragapus obscurus*), also a prey item of *A. gentilis laingi* (Ethier 1999; Lewis *et al.* 2006), may be particularly affected by understory vegetation removal by deer (Doyle 2004). Red Squirrels are the main prey of *A. gentilis laingi* throughout their range (Roberts 1997; Ethier 1999; Lewis *et al.* 2006), however they were not present on Haida Gwaii until 1947 when they were introduced to increase the endemic populations of Pine Marten (*Martes americana nesophila*). Red Squirrels are now the main summer prey of *A. gentilis laingi* on the islands (Doyle 2003b). It is unclear, however, how the introduction of Red Squirrels has influenced *A. gentilis laingi* populations, as the squirrels may negatively affect other goshawk prey through nest predation. Raccoons, a predator of *A. gentilis laingi* and their prey (Zwickel 1992; Laskeek Bay Conservation Society 1996; Hewitt *et al.* 2001), were introduced to Haida Gwaii in the 1940s to provide another source of fur for trappers. Furthermore, Black Rats (*Rattus rattus*) and Norway Rats (*Rattus norvegicus*) are two other persistent nest predators that may threaten prey populations of *A. gentilis laingi*. Black Rats were first verified on Haida Gwaii in 1919 (Laskeek Bay Conservation Society 1996) and Norway Rats were first observed in 1988, although they were probably introduced during the Second World War (Englestoft and Bland 2002). These possible food-web relationships on Haida Gwaii need to be tested by empirical data gathering and modelling (cf. Gurevitch and Padilla 2004; Clavero and Garcia-Berthou 2005) to better understand the threats they pose to *A. gentilis laingi* populations within the HG Conservation Region.

Depredation and competition

The conversion of forests to younger seral stages and increased fragmentation of forests may favour edge and open habitat species such as Red-tailed Hawks (*Buteo jamaicensis*), Barred Owls (*Strix varia*), and Great Horned Owls (*Bubo virginianus*) over interior forest species such

as *A. gentilis laingi*. Kenward (1996) hypothesized European Goshawk populations may be more adaptable to forest fragmentation than North American populations because of raptor guild differences. Red-tailed Hawks and several large owl species use Northern Goshawk nests for breeding and they often initiate breeding before Northern Goshawks and so there may be indirect competition for nest sites among these species (Campbell *et al.* 1990b; Doyle 2000). La Sorte *et al.* (2004) compared habitat characteristics around nests of Red-tailed Hawks and *A. gentilis atricapillus* in Arizona and found that their breeding habitats overlapped. However, Red-tailed Hawks selected more open forest nest sites adjacent to clearings whereas Northern Goshawks typically nested in denser forests, farther in from edges. Therefore, if nest sites of *A. gentilis laingi* occur in small (i.e., 12 ha), isolated fragments of forests, they may become more suitable for Red-tailed Hawks and this has been observed on Vancouver Island (Lindsay *et al.* 2004; E.L. McClaren, pers. observation, 1999). *Accipiter gentilis laingi* may compete for food with Red-tailed Hawks and large owls, although these potential competitors do not eat as many birds and they typically hunt in different habitat types (Bosakowski and Smith 1992). In Arizona, 48% of the diet of Red-tailed Hawks consisted of species that also occurred in the diets of *A. gentilis atricapillus* (Gatto *et al.* 2005). As well, Red-tailed Hawks, Great Horned Owls, and Bald Eagles (*Haliaeetus leucocephalus*) have been observed to kill adult, fledgling, and nestling Northern Goshawks (Rohner and Doyle 1992; Squires and Ruggiero 1995; Wiens 2004). It is difficult to predict the influence that habitat fragmentation and loss will have on predator/competitor communities, and the level of threat posed to *A. gentilis laingi* will vary by conservation region.

Climate change

The threats caused by climate change within coastal forests are unknown and are difficult to mitigate through this recovery strategy. Climate change may affect Northern Goshawk populations positively or negatively. Negative impacts may include altered microclimate conditions within coastal forests, changes in vegetation and species composition of forests (Hamann *et al.* 2006), altered prey abundance and availability, increased likelihood of forest fires, and diseases such as West Nile Virus and forest pest outbreaks (Hansen and Biringer 2003). Because weather and prey availability influence the reproduction and survival of Northern Goshawks (Doyle 2000; Dewey and Kennedy 2001; Bloxton 2002; Salafsky 2004; Wiens *et al.* 2006), climate change may impart a higher degree of annual **environmental stochasticity** on demographic rates, which may ultimately result in these relatively isolated populations of *A. gentilis laingi* becoming more susceptible to extirpation (Caughley and Gunn 1996). Alternatively, *A. gentilis laingi* may benefit from climate change if changes result in larger expanses of forest types that provide the structural attributes necessary for nesting and foraging, and support a greater abundance and diversity of prey species.

Human disturbance

Anecdotal evidence suggests that *A. gentilis laingi* are sensitive to disturbance at nest and roost sites (COSEWIC 2000), although some individuals are more tolerant than others (McLaughlin 2002; E.L. McClaren, pers. observation, 1998). The effect of human disturbance near nest and roost sites of *A. gentilis laingi* depends on the timing, intensity and proximity of the disturbance (Toyne 1997; COSEWIC 2000). The level of this threat may increase along with more road networks through forests, enabling greater levels of human access into remote areas.

Disease

West Nile Virus has not yet been documented within B.C.; however, it is as far west as Alberta in Canada and Washington and Oregon in the United States (H. Schwantje, pers. comm., 2005). West Nile Virus occurs in several bird species (including raptors; Nemeth *et al.* 2006) and the threat it poses to populations of *A. gentilis laingi* is unknown and difficult to predict (Komar *et al.* 2003; Marra *et al.* 2004). More information can be gained regarding the prevalence of infection from West Nile Virus to wild *A. gentilis laingi* by collecting tissue samples via feathers from captured individuals (H. Schwantje, pers. comm., 2005).

Human persecution

Although historic bounty hunting programs may have reduced populations of *A. gentilis laingi* near urban and agricultural centres in coastal areas, human persecution toward *A. gentilis laingi* is currently considered to be low and not a major threat (Table 2). There is a small chance that this threat is underestimated because of the recovery team's lack of knowledge of illegal persecution, especially of immature birds pursuing domestic fowl and racing pigeons (E.L. McClaren, pers. observation, 1999. B. Wijdeven, pers. observation, 2004; M. Buelow, pers. comm., 2005).

Actions Already Completed or Underway

Habitat Recovery Implementation Group (RIG)

The habitat RIG was formed in 2005. One of the first tasks of the RIG was to oversee development of a habitat model for *A. gentilis laingi* within each conservation region in B.C. Between 2005 and 2007, the habitat RIG developed models for nesting, foraging, and territories for HG, NC, and SC conservation regions (Marquis *et al.* 2005; Smith *et al.* 2007). As well, species experts in B.C. outlined habitat characteristics of *A. gentilis laingi* (Mahon *et al.* 2007). In 2007/2008, the Habitat RIG plans to complete habitat models for each conservation region, depending on funding and data availability. Between 2007 and 2009, the habitat RIG also plans to ground verify habitat model predictions for each conservation region to determine the accuracy and precision levels of models. To improve model predictions, habitat RIG members will revise habitat models based on the results of ground verification, where necessary. Refined habitat models will then be used to help the habitat RIG and recovery team to identify and delineate critical habitat in the action plan.

Inventory and monitoring

Structured inventory work for *A. gentilis laingi* occurred for 9 years on Vancouver Island (McClaren 2003) and is ongoing in Haida Gwaii (Doyle 2005). Monitoring programs are being carried out by forest licensees within some areas of Vancouver Island and throughout Haida Gwaii as part of an adaptive management strategy (Manning *et al.* 2003). The recovery team has initiated inventory work for *A. gentilis laingi* on the coastal mainland of B.C. in 2007.

Stewardship

The recovery team has initiated a program in Haida Gwaii to work with poultry farmers to report trapped *A. gentilis laingi*, to facilitate the collection of DNA samples and to assist the recovery team to assess the severity of this threat and to mitigate it, where necessary. As well, the recovery team is working to develop “science-based guidelines for working in and around *A. gentilis laingi* nesting and foraging habitats.”

Knowledge Gaps

The recovery team has identified knowledge gaps that are directly related to recovery planning and the success of recovery activities. Although the recovery team has a good knowledge base in several areas for *A. gentilis laingi*, there are many unknowns around what limits the population size of this subspecies. As well, the recovery team has better information on the habitat requirements of *A. gentilis laingi* at small scales relative to large scales. Data deficiencies were prioritized within each topic listed below based on perceived risks to our ability to recover *A. gentilis laingi* populations.

Habitat availability and requirements

1. Amount, distribution, and characteristics of critical habitat.
2. Relationship between habitat components and the reproduction and survival of *A. gentilis laingi*, and how forest harvesting affects these. This includes the degree of surrounding landscape contiguity that maintains successful breeding over time (e.g., the spatial relationship between foraging areas and PFAs).
3. Winter habitat associations.
4. Relationships between prey assemblages and foraging habitat characteristics.
5. Dispersal habitat characteristics.
6. Relationship between characteristics of breeding habitat and competition for nest sites.
7. Amount of suitable breeding and foraging habitat throughout the range of *A. gentilis laingi*, and the number of breeding pairs this habitat could support historically (pre-industrialized logging), currently and under future harvest scenarios.

Diet and prey availability

1. Breeding season diet in NC and SC conservation regions.
2. Winter diet in all conservation regions.
3. Change in prey abundance as a result of introduced species in HG conservation region.
4. Effects of annual fluctuations in weather patterns (e.g., El Niño and La Niña, on prey).

Population abundance and demographic parameters

1. Determine population abundance and trend estimates (i.e., population viability analyses and parameter sensitivity analyses):
 - a. annual occupancy rates of nest areas in NC and SC conservation regions;
 - b. monitoring of occupancy rates of known nest areas over time;
 - c. breeding density within NC and SC conservation regions;
 - d. average life span and number of reproductive years;
 - e. survival estimates (adult and juvenile);
 - f. immigration, emigration, dispersal, and recruitment rates; and
 - g. dispersal distances.
2. How competition for nests sites, siblicide, depredation of adults, young, and eggs, and climate regulate populations.

Population genetics and distribution

1. Genetic flow among conservation regions and refinement of the range boundaries for *A. gentilis laingi*.

Miscellaneous threats

1. Degree of risk posed by diseases/viruses such as West Nile Virus.
2. Degree of risk from climate change and the associated changes in habitat and prey assemblage that may follow.
3. Level of threat posed by human persecution and disturbance near nest sites.

RECOVERY

Recovery Feasibility

Based on its answers to criteria outlined in Environment Canada's draft policy on the feasibility of recovery (Environment Canada 2005), the recovery team determined that *A. gentilis laingi* was biologically and technically feasible to recover in B.C.:

1. **Are individuals capable of reproduction currently available to improve the population growth rate or population abundance? Yes.**
 - o An estimated 352–374 breeding pairs are present within B.C. (see Table 1) and some pairs are present in all conservation regions.
 - o Average offspring gender ratios of 50:50 within the VI conservation region (McClaren and Pendergast 2003) suggest an equal number of males and females entering the population (assuming survival and recruitment rates are approximately equal).
 - o There is evidence of successful breeding within each conservation region.
 - o Evidence of younger (<2 years) individuals reproducing suggests that the breeding population is not skewed towards only older individuals.

2. Is sufficient habitat available to support the species or could it be made available through habitat management or restoration? Yes.

- Individuals breed in mature second- and old-growth forests and so it is possible to recruit habitat after harvest.
- Permanent habitat loss (agriculture/urbanization) is minor (ca. 3%) throughout the Canadian range of *A. gentilis laingi*.

3. Can significant threats to the species or its habitat be avoided or mitigated through recovery actions? Yes.

- Significant threats listed in Table 2 and their mitigation actions include:
 - Habitat loss can be mitigated through reduced harvest levels, lengthened rotation periods, reforestation, and stand treatment activities to improve the structure of younger stands (e.g., spacing, pruning, and fertilization).
 - Habitat fragmentation can be mitigated through landscape-level planning, reduced harvest levels, lengthened rotation periods, and reforestation.
 - Introduced species within the HG conservation region that may result in increased depredation of adults, eggs, and young, and reduced prey availability can be mitigated through population control measures. Eradication of introduced species may not be technically feasible or economically viable.
 - Genetic isolation within the HG conservation region may be mitigated through translocation of individuals from surrounding conservation regions (although this may not be desirable if they are genetically distinct from adjacent populations) or re-introduction from captive breeding programs.

4. Do the necessary recovery techniques exist and are they demonstrated to be effective? Yes.

- Both *A. gentilis gentilis* and *A. gentilis atricapillus* exhibit the ability to rebound and re-establish themselves (naturally or via re-introduction) when populations have been reduced and excluded from portions of their range due to persecution and habitat destruction (Speiser and Bosakowski 1984; Petty 1989; Lensink 1997; Kennedy 1997, 2003), providing threats to populations were mitigated.

Recovery Goal

The long-term goal of this recovery strategy is to ensure viable populations of Northern Goshawk *A. gentilis laingi* persist in each conservation region in coastal British Columbia.

Recovery Objectives

This recovery strategy has the following objectives:

Objective 1:

To manage and, where necessary, conserve and recover habitat that meets the needs of Northern Goshawk *A. gentilis laingi* through its annual cycle.

Objective 2:

To conserve and, where necessary, recover a well-distributed and viable population of Northern Goshawk *A. gentilis laingi* within coastal B.C.

These objectives are broad at this time because the recovery team lacks basic information on the amount of suitable habitat available historically, relative to current supply and predicted future supplies (under different management scenarios), as well as population responses to habitat supply over time. Therefore, the recovery team has outlined a number of activities and associated timelines, which will help close these information gaps at which time the recovery objectives can be refined and updated.

Approaches Recommended to Meet Recovery Objectives

Recovery planning table

Table 3. Broad strategies that will be used to address threats and to achieve recovery of habitat and populations for *A. gentilis laingi*

Objective 1: To manage and, where necessary, conserve and recover habitat that meets the needs of the Northern Goshawk <i>A. gentilis laingi</i> through its annual cycle						
Threat(s) addressed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation region	Timeline (initiation-completion)
Habitat loss and fragmentation – nesting	Habitat protection	High	Protect known nest trees and PFAs	Pursue available tools for protection on public and private lands. See Appendix 1.	All	1999–2012
Habitat loss and fragmentation – nesting and foraging	Science-based guidelines for habitat management; stewardship	High	Manage nesting and foraging habitat that is required but cannot be included in Wildlife Habitat Areas (WHAs) for required forest attributes & human disturbance impacts	Develop science-based guidelines (incl. stand structure, seral stage distribution, human disturbance, access planning) for nesting and foraging habitat	All	2008
Habitat loss and fragmentation – foraging	Habitat management; stewardship	High	Develop land use designations for <i>A. gentilis laingi</i> foraging areas	Develop and implement general wildlife measures to ensure sufficient <i>A. gentilis laingi</i> foraging habitat outside WHAs is conserved	All	2008–2017

Objective 1: To manage and, where necessary, conserve and recover habitat that meets the needs of the Northern Goshawk <i>A. gentilis laingi</i> through its annual cycle						
Threat(s) addressed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation region	Timeline (initiation-completion)
Habitat loss and fragmentation – nesting and foraging	Research; habitat management guidelines	High	Identify habitat requirements for population goals	Use landscape modelling to identify the quality, abundance, and distribution of nesting and foraging habitat. This will assist the recovery team to determine where there are habitat deficits and where critical habitat needs to be delineated.	All	2005–2009
Habitat loss and fragmentation – nesting and foraging; prey diversity and availability	Research; habitat management guidelines	High	Recover sufficient habitat to support population goals	Research, develop and implement silvicultural techniques to promote stand attributes for the recovery, maintenance, and diversity of prey populations	All	1999–ongoing
Habitat loss and fragmentation – foraging; introduced species; prey diversity and availability	Research; habitat management guidelines; stewardship; outreach	High	Manage introduced species to minimize habitat impact	Develop and implement management plans for introduced species (e.g., deer) that are affecting foraging habitat and prey of <i>A. gentilis laingi</i>	HG	2008–ongoing

Objective 1: To manage and, where necessary, conserve and recover habitat that meets the needs of the Northern Goshawk <i>A. gentilis laingi</i> through its annual cycle						
Threat(s) addressed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation region	Timeline (initiation-completion)
Habitat loss and fragmentation – nesting and foraging; prey diversity and availability; introduced species; human disturbance	Stewardship; outreach	Medium	Engage public and private landowners, and resource managers in conserving habitat for <i>A. gentilis laingi</i>	Develop and implement outreach and education strategies for these groups	All	1995–ongoing
Habitat loss and fragmentation	Monitoring; adaptive management	High	Assess the effectiveness of habitat management actions to protect habitat of <i>A. gentilis laingi</i>	Conduct effectiveness monitoring as required	All	1995–ongoing
Research; habitat management guidelines	Research; habitat management guidelines	Low	Consider habitat management requirements over decadal time scales	Predict change in habitat attributes and distribution related to climate cycles and climate change scenarios, using climate modelling exercises	All	2012–2017

Objective 2: To conserve and, where necessary, recover a well-distributed and viable population of Northern Goshawk <i>A. gentilis laingi</i> within coastal B.C.						
Threat(s) addressed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation region	Timeline (initiation-completion)
Genetic isolation	Research; Population management guidelines	High	Define population and distribution objectives for each conservation region	• Use spatially explicit population modelling for each conservation region • Continue to collect and analyze genetic samples	All	2007–2009
Habitat loss and fragmentation-nesting and foraging; genetic isolation	Implement habitat management guidelines to manage populations; inventory; monitoring	High	Manage populations by conservation region to meet defined population and distribution objectives	• Use habitat conservation and management strategies defined under objective 1 to conserve and recover populations • Conduct inventory and monitoring as required	All	1999–ongoing 1995–ongoing
Introduced species; prey diversity and availability	Introduced species guidelines	High	Manage introduced species to minimize population impacts	• Develop and implement management plan for introduced species interactions affecting <i>A. gentilis laingi</i> indirectly (prey diversity and availability) and directly (predation)	HG	2008-ongoing
Prey diversity and availability	Monitoring; research	Medium	Assess and monitor prey abundance and diversity	• Determine primary prey species for <i>A. gentilis laingi</i> • Monitor prey populations and assess	NC, SC All	2008–2009 1994–ongoing

Objective 2: To conserve and, where necessary, recover a well-distributed and viable population of Northern Goshawk <i>A. gentilis laingi</i> within coastal B.C.						
Threat(s) addressed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation region	Timeline (initiation-completion)
				impacts of forest harvest techniques on prey		
Persecution	Stewardship; outreach; research	Low	Assess threat to <i>A. gentilis laingi</i> from persecution and reduce if required	- Evaluate degree of risk to <i>A. gentilis laingi</i> posed by persecution - Address persecution issues through outreach and education strategies, if required	All	2006–2012
Disease	Monitoring; research	Low	Monitor for presence of West Nile Virus and other potential diseases	Design and implement monitoring program for WNV (model potential impacts)	All	2015–2017
Competition, depredation	Monitoring; research	Low	Monitor populations of edge-adapted predators and competitors	Design and implement a monitoring program for edge-adapted competitors and predators (e.g., Red-tailed Hawks, Great Horned Owls, Barred Owls)	All	2010–2012

Performance Measures

Key performance measures are identified below.

- Are known nest trees and PFA's protected by 2012?
- Have population and distribution objectives been defined for each conservation region by 2009?
- Have habitat requirements for population goals been identified by 2009?
- Have science-based guidelines been developed by 2008?
- Has prey abundance and diversity been assessed and monitoring been initiated by 2009?
- Have threats from prosecution been assessed and reduced, if required, by 2012?
- Has monitoring of populations of edge-adapted predators and competitors been initiated by 2012?

Critical Habitat

Identification of the species' critical habitat

Critical habitat is defined in the *Species at Risk Act* as habitat that is necessary for the survival (current) or recovery (future recruitment) of a listed species (Environment Canada 2006). Within this recovery strategy, the recovery team describes the biophysical attributes of habitat components for *A. gentilis laingi* (see "Habitat needs" section).

Critical habitat cannot be defined at this time. The recovery team feels that it has insufficient information regarding both the amount and location of suitable habitat within each conservation region to be able to confidently determine which areas are necessary to meet the recovery goal. As well, without population modelling, the team cannot set meaningful population objectives for each conservation region.

Recommended schedule of studies to identify critical habitat

The recovery team lacks information to develop numerically bound and measurable population and habitat targets for *A. gentilis laingi*. Most of the following activities will be carried out by the habitat RIG and the results incorporated into an action plan, with strategic direction and periodic review from the recovery team.

Steps required to establish habitat and population targets for *A. gentilis laingi* are outlined in Table 4.

Table 4. Steps necessary to establish measurable and science-based habitat and population objectives and to delineate critical habitat for *A. gentilis laingi* within each conservation region in B.C.

Activity	Timeline ^a	Status
Develop habitat suitability (nesting and foraging) and territory models for <i>A. gentilis laingi</i> within each conservation region	2007–2008	In progress
Develop standards for ground verification of habitat suitability models	2006–2007	Complete

Verify habitat suitability models within each conservation region and refine models accordingly	2006–2009	In progress
Use habitat suitability models to assess quantity, quality, and distribution of nesting and foraging habitat within each conservation region	2008–2009	In progress
Develop a population model for each conservation region in B.C. and overlay this with the habitat suitability model so that it is spatially explicit	2008–2009	Not yet initiated
Determine viable population targets for each conservation region	2009	Not yet initiated
Determine habitat targets and distribution for each conservation region	2008–2009	Not yet initiated
Delineate survival and recovery habitat (action plan) for populations by conservation region	2008–2010	Not yet initiated

^a ability to meet anticipated deadlines will depend on funding availability.

Existing and Recommended Approaches to Habitat Protection

See Appendix 1 for existing approaches and measures available to protect habitat for *A. gentilis laingi*.

Effects on Other Species

Several species that select habitat characteristics similar to *A. gentilis laingi* will benefit from implementation of this recovery strategy. Specifically, recovery processes involving Marbled Murrelets, Spotted Owls, and Coastal Douglas-fir (CDFmm1) ecosystems will likely benefit from this recovery strategy. Although *A. gentilis laingi* prey upon Marbled Murrelets and Spotted Owls, they could potentially regulate populations of other predators of these species and they provide nest platforms for Spotted Owls (Forsman and Giese 1997). As well, prey species of *A. gentilis laingi* such as grouse, woodpeckers, small forest owls, and Red Squirrels will benefit from habitat management aimed at improving foraging habitat of this subspecies. To the best of our knowledge, no SARA-listed species will be negatively impacted through implementation of this recovery strategy.

Socioeconomic Considerations

A detailed socioeconomic cost–benefit analysis (SEA) is not required in a recovery strategy but will accompany the recovery action plan(s). The recovery team deemed it prudent, however, to note the scale of potential socioeconomic impacts of recovery.

Because of the extensive spatial requirements for nesting, post-fledging, and foraging, recovery of *A. gentilis laingi* may have a substantial impact on coastal B.C.'s forested landbase (see Figure 1). Activities affected include mainly forest harvesting, but may also include non-timber forest harvesting for mining, power generation, recreation, agriculture, and housing. Recovery may also impact both First Nations economic and traditional use practices. Promoting

stewardship activities and creating incentive packages, especially on private lands, may be required to address action plan needs.

While there are economic costs associated with recovery of *A. gentilis laingi*, the benefits associated with ecosystem maintenance and habitat protection are more difficult to quantify economically. The citizens of B.C. have consistently expressed strong support for protection of species at risk. This support is reflected in the government's stated goal to lead the world in sustainable environmental management (Speech from the Throne, Opening of the Sixth Session, Thirty-Seventh Parliament of the Province of British Columbia, February 8, 2005). Furthermore, substantial social, political, and economic benefits are likely involved in recovery of the species including compliance with the federal *Species at Risk Act* (SARA) and avoidance or reduction of costs related to captive breeding programs.

Anticipated Conflicts

Northern Goshawks have been at the centre of debate surrounding forest harvesting practices throughout North America (Crocker-Bedford 1990, 1998; Kennedy 1997; Daw *et al.* 1998; Andersen *et al.* 2003; Kennedy 2003; McGrath *et al.* 2003) and Europe (Widén 1997) for over a decade. Several petitions have been launched by environmental organizations and concerned citizens to list *A. gentilis laingi* under the U.S. *Endangered Species Act* (see U.S. litigation review in Squires and Kennedy 2006). As soon as forests become structurally mature and suitable for *A. gentilis laingi*, they also become economically viable for timber harvesting. The recovery team anticipates that there may be conflict associated with maintaining a sufficient amount of habitat for the survival and recovery of populations of *A. gentilis laingi* and with continuing to manage forests at current allowable annual harvest levels and rotation periods within coastal B.C.

Threats to *A. gentilis laingi* from introduced species in Haida Gwaii may be challenging to overcome. Forest fragmentation has the potential to increase depredation of adults, eggs, and young, and increase competition for nest sites for *A. gentilis laingi*, which may be difficult to mitigate. As well, the recovery team is unsure how it will be able to reduce threats posed by emerging diseases (e.g., West Nile Virus) and climate change within our action plan. Importantly, the recovery team anticipates challenges associated with obtaining sufficient funding to fill the knowledge gaps that have been identified (see "Knowledge Gaps" section).

Recommended Approach for Recovery Implementation

This recovery strategy for *A. gentilis laingi* was developed for the four conservation regions in B.C. (see "Global distribution" section). Although these conservation regions may not encompass discrete populations, each region has its own suite of threats and management issues. Therefore, recovery activities must occur at multiple scales including conservation regions, watersheds within conservation regions, and potential home ranges. Reynolds *et al.* (1992) have implemented this approach in southeastern Arizona where forested landscapes are managed for foraging and nesting habitats as well as for prey species. Because of the high site fidelity exhibited by this species, conservation measures within B.C.'s conservation regions have historically focused on sites known to contain breeding pairs. However, managing *A. gentilis*

laingi on a nest-by-nest basis is an ineffective management approach at a population scale because individuals have large breeding and winter home ranges and they build multiple nests within breeding areas throughout their lifetime. Additionally, *A. gentilis laingi* are difficult to detect and locating all nests within a breeding home range is virtually impossible because nests will fall out of trees over time and new nests will be constructed. The recovery team recommends addressing the management of *A. gentilis laingi* at a landscape or watershed level to ensure that suitable breeding, foraging, and wintering habitats exist throughout the landscape. Ultimately, a multi-scale approach will be necessary to ensure the recovery of *A. gentilis laingi*. A multi-scale approach will require that sufficient levels of foraging habitat be maintained within close proximity to suitable nesting habitat, and that habitat among pairs is sufficient in amount and distribution to facilitate successful dispersal and mate-pairing to maintain healthy populations.

Statement on Action Plans

The Habitat RIG plans to complete an action plan within 2 years after final posting on the B.C. government website of the recovery strategy (as outlined in Table 4).

REFERENCES

- Allombert, S., A.J. Gaston, and J.L. Martin. 2005a. A natural experiment on the impact of overabundant deer on forest invertebrates. *Conserv. Biol.* 19:1917–1929.
- _____. 2005b. A natural experiment on the impact of overabundant deer on songbird populations. *Biol. Conserv.* 126:1–13.
- American Ornithologists' Union (AOU). 1957. Check-list of North American birds. 5th ed. Baltimore, MD.
- _____. 1983. Checklist of North American birds. 6th ed. Allen Press, Lawrence, KS.
- Andersen, D.E., S. DeStefano, M.I. Goldstein, K. Titus, C. Crocker-Bedford, J.J. Keane, R.G. Anthony, and R.N. Rosenfield. 2003. The status of Northern Goshawks in the western United States. The Wildlife Society, Bethesda, MD. *Wildl. Soc. Tech. Rev.* 04-1. 24 pp.
- Bayard de Volo, S., R.T. Reynolds, J.R. Topinka, B. May, and M.F. Antolin. 2005. Population genetics and genotyping for mark-recapture studies of Northern Goshawks (*Accipiter gentilis*) on the Kaibab Plateau, AZ. *J. Raptor Res.* 39:286–295.
- Beebe, F.L. 1974. Field studies of the Falconiformes of British Columbia. B.C Provincial Museum, Victoria, BC. Occasional Paper No. 17.
- Beier, P. and J.E. Drennan. 1997. Forest structure and prey abundance in foraging areas of Northern Goshawks. *Ecol. Appl.* 7:564–571.
- Bloxton, T.D., Jr. 2002. Prey abundance, space use, demography, and foraging habitat of Northern Goshawks in Western Washington. M.Sc. thesis. Univ. Washington, Seattle, WA.
- Boal, C.W. 1994. A photographic and behavioral guide to aging nestling Northern Goshawks. *Stud. Avian Biol.* 16:32–40.
- Boal, C.W., D.E. Andersen, and P.L. Kennedy. 2003. Home range and residency status of Northern Goshawks breeding in Minnesota. *Condor* 105:811–816.
- _____. 2005. Foraging and nesting habitat of breeding male Northern Goshawks in the Laurentian Mixed Forest Province, Minnesota. *J. Wildl. Manage.* 69:1516–1527.
- Bond, R.M. and R.M. Stabler. 1941. Second-year plumage of the goshawk. *Auk* 58:346–349.
- Bosakowski, T. and D.G. Smith. 1992. Comparative diets of sympatric nesting raptors in the eastern deciduous forest biome. *Can. J. Zool.* 70:984–992.

- British Columbia Conservation Data Centre. 2005. B.C. Species and Ecosystems Explorer. B.C. Min. Environ., Victoria, BC. <<http://srmapps.gov.bc.ca/apps/eswp/>> Accessed [Nov. 20, 2005]
- British Columbia Ministry of Forests. 1995. Biodiversity guidebook. Victoria, BC. Forest Practices Code of B.C. Guidebook.
- Broberg, L.E. 1997. Draft population viability analysis of the Queen Charlotte Goshawk (*Accipiter gentilis laingi*) in southeastern Alaska. Unpublished report.
- Burleigh, J. and J. Hodge. 2004. Coastal Forest Region forest health strategy. Phero Tech Inc. and JCH Forest Pest Management. Delta, BC. Unpublished report.
- Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, and M.C.E. McNall. 1990a. The birds of British Columbia. Vol. I: nonpasserines. Royal B.C. Museum, Victoria, BC.
- _____. 1990b. The birds of British Columbia. Vol. II: nonpasserines. Royal B.C. Museum, Victoria, BC.
- Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, M.C.E. McNall, and G.E.J. Smith. 1990c. The birds of British Columbia. Vol. III: passerines. Royal B.C. Museum, Victoria, BC.
- Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, A.C. Stewart, and M.C.E. McNall. 1990d. The birds of British Columbia. Vol. IV: passerines. Royal B.C. Museum, Victoria, BC.
- Caughley, G. and A. Gunn. 1996. Conservation biology in theory and practice. Blackwell Science Inc., Cambridge, MA.
- Chytky, P. and K. Dhanwant. 1997. 1996 Northern Goshawk population inventory of the Queen Charlotte Islands / Haida Gwaii. B.C. Min. Environ., Lands and Parks, Smithers, BC. Unpublished report.
- Clavero, M. and E. Garcia-Berthou. 2005. Invasive species are a leading cause of animal extinctions. Trends Ecol. Evol. 20:110.
- Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2000. COSEWIC assessment and update status report on the Northern Goshawk *laingi* subspecies *Accipiter gentilis laingi* in Canada. Ottawa, ON. vi + 36 pp.
<www.sararegistry.gc.ca/status/status_e.cfm> Accessed. December 2007
- Cooper, J.M. and V. Stevens. 2000. A review of the ecology, management and conservation of the Northern Goshawk in British Columbia. B.C. Min. Environ., Lands and Parks, Victoria, BC. Wildl. Bull. B-101.

- Crocker-Bedford, D.C. 1990. Goshawk reproduction and forest management. Wildl. Soc. Bull. 18:262–269.
- _____. 1994. Conservation of the Queen Charlotte Goshawk in Southeast Alaska. Report to Alaska Region of the U.S. Forest Service. 40 pp.
- _____. 1998. The value of demographic and habitat studies in determining the status of Northern Goshawks (*Accipiter gentilis atricapillus*) with special reference to Crocker-Bedford (1990) and Kennedy (1997). J. Raptor Res. 32:329–335.
- Daw, S., S. DeStefano, and R.J. Steidl. 1998. Does search method bias the description of Northern Goshawk nest-site selection? J. Wildl. Manage. 62:1378–1383.
- Desimone, S.M. and D.W. Hays. 2004. Northern Goshawk *Accipiter gentilis*. Vol. IV. Birds. Washington Dep. Fish and Wildlife, WA. 17 pp.
- DeStefano, S. 1998. Determining the status of Northern Goshawks in the west: is our conceptual model correct? J. Raptor Res. 32:342–348.
- Dewey, S.R. and P.L. Kennedy. 2001. Effects of supplemental food on parental-care strategies and juvenile survival of Northern Goshawks. Auk 118:352–365.
- Doyle, F.I. 2000. Timing of reproduction by Red-tailed Hawks, Northern Goshawks and Great Horned Owls in the Kluane Boreal Forest of southwestern Yukon. M.Sc. thesis. Univ. B.C., Vancouver, BC.
- _____. 2003a. Biological review and recommended interim strategy direction for Northern Goshawks on Haida Gwaii/Queen Charlotte Islands. Wildlife Dynamics Consulting, Telkwa, BC. Unpublished report.
- _____. 2003b. Managing for goshawks in TFL 39 on Haida Gwaii/Queen Charlotte Islands: goshawk nest monitoring and diet in 2003. Wildlife Dynamics Consulting, Telkwa, BC. Unpublished report.
- _____. 2004. Blue Grouse habitat on Haida Gwaii/Queen Charlotte Islands. Wildlife Dynamics Consulting, Telkwa, BC. Unpublished report.
- _____. 2005. Breeding success of the goshawk (*A. gentilis laingi*) on Haida Gwaii/Queen Charlotte Islands 2005: is the population continuing to decline? Wildlife Dynamics Consulting, Telkwa, BC. Unpublished report.
- _____. 2006. When do naturally regenerating and pre-commercially thinned second-growth forests attain attributes that will support Northern Goshawk (*laingi* subspecies) and Marbled Murrelets on Haida Gwaii? Wildlife Dynamics Consulting, Telkwa, BC. Unpublished report.

- Doyle, F.I. and D. McLennan. 2003. Goshawk territory distribution, nest and foraging area requirements and a habitat assessment of predicted nest areas, both in TFL 39 and in the adjacent landscape, on the Queen Charlotte Islands/Haida Gwaii. Wildlife Dynamics Consulting, Telkwa, BC. Unpublished report.
- Doyle, F.I. and J.M.N. Smith. 1994. Population responses of Northern Goshawks to the 10-yr cycle in numbers of snowshoe hares. *Stud. Avian Biol.* 16:122–129.
- Drennan, J.E. and P. Beier. 2003. Forest structure and prey abundance in winter habitat of Northern Goshawks. *J. Wildl. Manage.* 67:177–185.
- Duncan, P. and D.A. Kirk. 1994. Status report on the Queen Charlotte Goshawk *Accipiter gentilis laingi* and Northern Goshawk *Accipiter gentilis atricapillus* in Canada. Environ. Can., Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON.
- Dunne, P., D. Sibley, and C. Sutton. 1988. Hawks in flight. Houghton Mifflin Company, Boston, MA.
- Engletoft, C. and L. Bland. 2002. Restoration priorities associated with introduced species impacts on Haida Gwaii/Queen Charlotte Islands: perspectives and strategies. Alula Biological Consulting, Saanichton, BC. Unpublished report.
- Environment Canada. 2005. Draft policy on feasibility of recovery. Environ. Can., Species at Risk Recovery Program, Ottawa, ON.
- _____. 2006. Draft policy on the identification and protection of critical habitat under SARA, version 2.5. Species at Risk Recovery Program, Ottawa, ON.
- Estes, W.A., S.R. Dewey, and P.L. Kennedy. 1999. Siblicide at Northern Goshawk nests: does food play a role? *Wilson Bull.* 111:432–436.
- Ethier, T.J. 1999. Breeding habitat of Northern Goshawks (*Accipiter gentilis laingi*) on Vancouver Island: a hierarchical approach. M.Sc. thesis. Univ. Victoria, Victoria, BC.
- Finn, S.P., D.E. Varland, and J.M. Marzluff. 2002. Does Northern Goshawk breeding occupancy vary with nest-stand characteristics on the Olympic Peninsula, Washington? *J. Raptor Res.* 36:265–277.
- Flatten, C.J. and E.L. McClaren. In prep. Size and color variation of Northern Goshawks from southeast Alaska and Vancouver Island.
- Flatten, C., K. Titus, and R. Lowell. 2001. Northern Goshawk monitoring, population ecology and diet on the Tongass National Forest. Alaska Dep. Fish and Game, Juneau, AK. Unpublished report.

- Forest and Range Practices Act. 2004. B.C. Ministry of Forests and Range, Victoria, B.C.: <<http://www.for.gov.bc.ca/tasb/legsregs/frpa/frpa/frpatoc.htm>> Accessed [Aug. 2, 2006]
- Forsman, E.D. and A.R. Giese. 1997. Nests of Northern Spotted Owls on the Olympic Peninsula, Washington. *Wilson Bull.* 109:28–41.
- Gatto, A.E., T.G. Grubb, and C.L. Chambers. 2005. Red-tailed Hawk dietary overlap with Northern Goshawks on the Kaibab Plateau, Arizona. *J. Raptor Res.* 39:439–444.
- Gavin, T.A. and B. May. 1996. Genetic variation and taxonomic status of Northern Goshawks in Arizona: implications for management. Unpublished final report.
- Golumbia, T., L. Bland, K. Moore, and P. Bartier. In press. History and current status of introduced vertebrates on Haida Gwaii (Queen Charlotte Islands). *Can. Wildl. Serv. Occasional Paper*. March 16, 1996. Cornell University, NY.
- Green, R.N. and K. Klinka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. B.C. Min. For., Victoria, BC. *Land Manage. Handb.* No. 28.
- Greenwald, D.N., D.C. Crocker-Bedford, L. Broberg, K.F. Suckling, and R. Tibbitts. 2005. A review of Northern Goshawk habitat selection in the home range and implications for forest management in the western United States. *Wildl. Soc. Bull.* 33:120–129.
- Greenwood, P.J. 1980. Mating systems, philopatry and dispersal in birds and mammals. *Anim. Behav.* 28:1140–1162.
- Gurevitch, J. and D.K. Padilla. 2004. Are invasive species a major cause of extinctions? *Trends Ecol. Evol.* 19:470–474.
- Hall, L.S., P.R. Krausman, and M.L. Morrison. 1997. The habitat concept and a plea for standard terminology. *Wildl. Soc. Bull.* 25:173–182.
- Hamann, A., T. Wang, S.N. Aitken, and A. Yanchuk. 2006. Potential effects of climate change on ecosystems, tree species distributions, gene conservation, and genetic resource management in British Columbia. *Ecology* 87:2773–2786.
- Hansen, L.J. and J.L. Biringer. 2003. *Buying time: a user's manual for building resistance and resilience to climate change in natural systems*. World Wildlife Fund Climate Change Program, Berlin, Germany.
- Havera, S.P. and R.E. Duzan. 1986. Organochlorines and PCB residues in tissues of raptors from Illinois, 1966–1981. *Bull. Environ. Contam. Toxicol.* 36:23–32.
- Hewitt, D.G., D.M. Keppie, and D.F. Stauffer. 2001. Predation effects on forest grouse recruitment. *Wildl. Soc. Bull.* 29:16–23.

- Holt, R.F. 2004. Environmental conditions report for the Haida Gwaii/Queen Charlotte Islands Land Use Plan. Veridian Ecological Consulting Ltd., Nelson, BC. Unpublished report.
- Hunt, W.G. 1998. Raptor floaters at Moffat's equilibrium. *Oikos* 82:191–197.
- Iverson, G.C., G.D. Hayward, K. Titus, E. DeGayner, R.E. Lowell, D.C. Crocker-Bedford, P.F. Schempf, and J. Lindell. 1996. Conservation assessment for the Northern Goshawk in southeast Alaska. U.S. Dep. Agric. For. Serv. Publ. PNW-GTR-387.
- Jewett, S.A., W.A. Taylor, W.T. Shaw, and J.W. Aldrich. 1953. Birds of Washington state. Univ. Washington Press, Seattle, WA. 767 pp.
- Johnson, D.R. 1989. Body size of Northern Goshawks on coastal islands of British Columbia. *Wilson Bull.* 101:637–639.
- Keane, J. 1999. Ecology of the Northern Goshawk in the Sierra Nevada, California. Ph.D. dissertation. Univ. California, Davis, CA.
- Keane, J.J., M.L. Morrison, and D.M. Fry. 2006. Prey and weather factors associated with temporal variation in Northern Goshawk reproduction in the Sierra Nevada California. *Stud. Avian Biol.* 31:85–99.
- Kennedy, P.L. 1997. The Northern Goshawk (*Accipiter gentilis atricapillus*): is there evidence of a population decline? *J. Raptor Res.* 31:95–106.
- _____. 2003. Northern Goshawk (*Accipiter gentilis atricapillus*): a technical conservation assessment. U.S. Dep. Agric. For. Serv., Rocky Mountain Region, Species Conservation Project. 131 pp.
- Kennedy, P.L. and J.M. Ward. 2003. Effects of experimental food supplementation on movements of juvenile Northern Goshawk (*Accipiter gentilis atricapillus*). *Oecologia* 134:284–291.
- Kennedy, P.L., J.M. Ward, G.A. Rinker, and J.A. Gessamen. 1994. Post-fledging areas in Northern Goshawk home ranges. *Stud. Avian Biol.* 16:75–82.
- Kenward, R.E. 1982. Goshawk hunting behaviour, and range size as a function of food and habitat availability. *J. Anim. Ecol.* 51:69–80.
- _____. 1996. Goshawk adaptation to deforestation: does Europe differ from North America? Pages 233–243 in *Raptors in human landscapes*. D.M. Bird, D.E. Varland, and J.J. Negro, eds. Academic Press, New York, NY.

- Kenward, R.E., V. Marcström, and M. Karlbom. 1999. Demographic estimates from radio-tagging: models of age-specific survival and breeding in goshawk. *J. Anim. Ecol.* 68:1020–1033.
- Komar, N., S. Langevin, S. Hinten, N. Nemeth, E. Edwards, D. Hettler, B. Davis, R. Bowen, and M. Bunning. 2003. Experimental infection of North American birds with the New York 1999 strain of West Nile Virus. *Emerg. Infect. Dis.* 3:311–322.
- Kostrzewa, A. and R. Kostrzewa. 1990. The relationship of spring and summer weather with density and breeding performance of the buzzard *Buteo buteo*, goshawk *Accipiter gentilis*, and kestrel *Falco tinnunculus*. *Ibis* 132:550–559.
- Kostrzewa, R. and A. Kostrzewa. 1991. Winter weather, spring and summer density, and subsequent breeding success of Eurasian Kestrels, Common Buzzards and Northern Goshawks. *Auk* 108:342–347.
- Kramer, M.G., A.J. Hansen, M.L. Taper, and E.J. Kissinger. 2001. Abiotic controls on long-term windthrow disturbance and temperate rain forest dynamics in southeast Alaska. *Ecology* 82:2749–2768.
- Krüger, O. 2002. Interactions between Common Buzzard *Buteo buteo* and goshawk *Accipiter gentilis*: trade-offs revealed by a field experiment. *Oikos* 96:441–452.
- _____. 2005. Age at first breeding and fitness in goshawk *Accipiter gentilis*. *J. Anim. Ecol.* 74:266–273.
- Krüger, O. and J. Lindström. 2001. Habitat heterogeneity affects population growth in goshawk *Accipiter gentilis*. *J. Anim. Ecol.* 70:173–181.
- Laskeek Bay Conservation Society. 1996. Newsletter. No. 3. Queen Charlotte City, BC. 12 pp.
- La Sorte, F.A., R.W. Mannan, R.T. Reynolds, and T.G. Grubb. 2004. Habitat associations of sympatric Red-tailed Hawks and Northern Goshawks on the Kaibab Plateau. *J. Wildl. Manage.* 68:307–317.
- Lensink, R. 1997. Range expansion of raptors in Britain and the Netherlands since the 1960s: testing an individual-based Diffusion Model. *J. Anim. Ecol.* 66:811–826.
- Lewis, S.B., K. Titus, and M.R. Fuller. 2006. Northern Goshawk diet during the nesting season in Southeast Alaska. *J. Wildl. Manage.* 70:1151–1160.
- Lindén, H. and M. Wikman. 1983. Goshawk predation on tetraonids: availability of prey and diet of the predator in the breeding season. *J. Anim. Ecol.* 52:953–968.
- Lindsay, D., K. Lindsay, and L. Menzies. 2004. Northern Goshawk nesting inventory 2004. TimberWest Ltd., Duncan, BC. Unpublished report.

- MacArthur, R.H. and E.O. Wilson. 1967. The theory of island biogeography. Princeton Univ. Press, Princeton, NJ.
- Mackenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.I. Bailey, and J.E. Hines. 2006. Occupancy estimation and modelling. Academic Press, Boston, MA.
- Mackie, R.S. 2000. Island timber. Sono Nis Press, Victoria, BC.
- MacKinnon, A., D. Meidinger, and K. Klinka. 1992. Use of the biogeoclimatic ecosystem classification system in British Columbia. For. Chron. 68:100–120.
- Mahon, T., F.I. Doyle, and D. Morgan. 2003. Northern Goshawk (*Accipiter gentilis*??) habitat in the North Coast Forest District. Foraging area and nest area habitat suitability models. Wildfor Consultants Limited, Telkwa, BC. Unpublished report.
- Mahon, T., E.L. McClaren, and F. Doyle. 2007. Parameterization of the Northern Goshawk (*Accipiter gentilis laingi*) habitat model for Coastal British Columbia. Produced for the Northern Goshawk Recovery Team and Habitat RIG. Draft. Unpublished report.
- Manning, E.T., J.M. Cooper, and J.A. Deal. 2003. Queen Charlotte Goshawk adaptive management strategy TFL 37. Manning, Cooper and Associates, Victoria, BC. Unpublished report.
- Marchak, M.P., S.L. Aycock, and D.M. Herbert. 1999. Falldown: forest policy in British Columbia. David Suzuki Foundation and Ecotrust Canada, Vancouver, BC.
- Marcström, V. and R. Kenward. 1981. Sexual and seasonal variation in condition and survival of Swedish goshawks *Accipiter gentilis*. Ibis 123:311–327.
- Marquis, D., T. Piepjohn, and B. Lasuta. 2005. Study of breeding habitat and possible threats from timber harvesting activities to the Northern Goshawk (*Accipiter gentilis laingi*) coastal, British Columbia. Terminal Forest Products, Ltd., Richmond, BC. Unpublished report.
- Marra, P.P., S. Griffing, C. Caffrey, A.M. Kilpatrick, R. McLean, C. Brand, E. Saito, A.P. Dupuis, L. Kramerand, and R. Novak. 2004. West Nile Virus and wildlife. BioScience 54:393–402.
- Martin, J.L. and C. Baltzinger. 2002. Interaction among deer browsing, hunting, and tree regeneration. Can. J. For. Res. 32:1254–1264.
- Martin, J.L., M. Joron, and A.J. Gaston. 2001. The squirrel connection: influence of squirrels as songbird nest predators in Laskeek Bay. Laskeek Bay Research No. 10. Queen Charlotte City, BC. pp. 43–60.

- McClaren, E.L. 2003. Northern Goshawk (*Accipiter gentilis laingi*) population inventory summary for Vancouver Island 1994–2002. B.C. Min. Water, Land and Air Protection, Nanaimo, BC. Unpublished report.
- McClaren, E.L., P.L. Kennedy, and P.L. Chapman. 2003. Efficacy of male goshawk food-delivery calls in broadcast surveys on Vancouver Island. *J. Raptor Res.* 37:198–208.
- McClaren, E.L., P.L. Kennedy, and S.R. Dewey. 2002. Do some Northern Goshawk nest areas consistently fledge more young than others? *Condor* 104:343–352.
- McClaren, E.L., P.L. Kennedy, and D.D. Doyle. 2005. Northern Goshawk (*Accipiter gentilis laingi*) post-fledging areas on Vancouver Island, British Columbia. *J. Raptor Res.* 39:253–263.
- McClaren, E.L. and C.L. Pendergast. 2003. Relationship between forest age class distribution around Northern Goshawk nests and occupancy and nest productivity patterns at three spatial scales. B.C. Min. Water, Land and Air Protection, Nanaimo, BC. Unpublished report.
- McGowan, J.D. 1975. Distribution, density and productivity of goshawks in interior Alaska. Alaska Dep. Fish and Game, Juneau, AK. Unpublished report.
- McGrath, M.T., S. DeStefano, R.A. Riggs, L.L. Irwin, and G.J. Roloff. 2003. Spatially explicit influences on Northern Goshawk nesting habitat in the interior Pacific Northwest. *Wildl. Monogr.* 154:1–63.
- McLaughlin, R.T. 2002. Northern Goshawk nest monitoring on Br 128, Sproat Lake Timberlands. Nanaimo Woodlands, B.C. Coastal Group, Nanaimo, BC. Unpublished report.
- Nagorsen, D. 2002. An identification manual to the small mammals of British Columbia. B.C. Min. Sustainable Resource Manage., B.C. Min. Water, Land and Air Protection, and Royal B.C. Museum, Victoria, BC.
- _____. 2005. Rodents and lagomorphs of British Columbia. Royal B.C. Museum, Victoria, BC.
- National Geographic Society. 1999. Field guide to the birds of North America. 3rd ed. Washington, DC.
- Nemeth, N., D. Gould, R. Bowen, and N. Komar. 2006. Natural and experimental West Nile virus infection in five raptor species. *J. Wildl. Dis.* 42:1–13.
- Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, SD.
- _____. 1991. Population limitation in birds: a comparative approach. In C.M. Perrins, J.D. Peberon, and G.M. Hirons, eds. Bird population studies. Oxford Univ. Press, Oxford, UK.

- Newton, I., M. Marquiss, and A. Village. 1983. Weights, breeding, and survival in European Sparrowhawks. *Auk* 100:344–354.
- Palmer, R.S. 1988. Northern Goshawks. Pages 355–378 in R.S. Palmer, ed. *The handbook of North American Birds - Volume 4: diurnal raptors*. Yale Univ. Press, New Haven, CT.
- Patla, S.M. 1997. Nesting ecology and habitat of the Northern Goshawk in undisturbed and timber harvest areas of the Targhee National Forest, Greater Yellowstone Ecosystem. M.Sc. thesis. Idaho State Univ., Boise, ID.
- Pearse, P. 2001. Ready for change: crisis and opportunity in the coast forest industry. A report to the Ministry of Forests on B.C.'s coastal forest industry sector. Vancouver, BC.
- Penteriani, V. 1997. Long-term study of a goshawk breeding population on a Mediterranean mountain (Abruzzi Apennines, Central Italy): density, breeding performance and diet. *J. Raptor Res.* 31:308–312.
- Penteriani, V., M. Mathiaut, and G. Boisson. 2002. Immediate species responses to catastrophic natural disturbances: windthrow effects on density, productivity, nesting stand choice and fidelity in Northern Goshawks (*Accipiter gentilis*). *Auk* 119:1132–1137.
- Petty, S.J. 1989. Goshawks: their status, requirements and management. For: Commission Bull. 81:1–17.
- Reich, R.M., S.M. Joy, and R.T. Reynolds. 2004. Predicting the location of Northern Goshawk nests: modeling the spatial dependency between nest locations and forest structure. *Ecol. Model.* 176:109–133.
- Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Bassett, P.L. Kennedy, D.A. Boyce Jr., G. Goodwind, R. Smith, and E.L. Fisher. 1992. Management recommendations for the Northern Goshawk in the southwestern United States. U.S. Dep. Agric. For. Serv., Fort Collins, CO. Gen. Tech. Rep. RM-217.
- Reynolds, R.T. and S.M. Joy. 1998. Distribution, territory occupancy, dispersal, and demography of Northern Goshawks on the Kaibab Plateau, AZ. Arizona Game and Fish. Heritage Project No. I94045.
- _____. 2006. Demography of Northern Goshawks in Northern Arizona 1991–1996. *Stud. Avian Biol.* 31:63–74.
- Reynolds, R.T., S.M. Joy, and D.G. Leslie. 1994. Nest productivity, fidelity and spacing of Northern Goshawks in northern Arizona. *Stud. Avian Biol.* 16:106–111.

- Reynolds, R.T., S.M. Joy, J.D. Wiens, S. Salafsky, and J. Seyfried. 2000. Territory and mate fidelity and natal and breeding dispersal in an insular population of Northern Goshawk. U.S. Dep. Agric. For. Serv., Fort Collins, CO. Unpublished report.
- Reynolds, R.T. and E.C. Meslow. 1984. Partitioning of food and niche characteristics of coexisting *Accipiter* during breeding. *Auk* 101:761–779.
- Reynolds, R.T., G.C. White, S.M. Joy, and R.W. Mannan. 2004. Effects of radio transmitters on Northern Goshawks: do tailmounts lower survival of breeding males? *J. Wildl. Manage.* 68:25–32.
- Reynolds, R.T., J.D. Wiens, and S.R. Salafsky. 2006. A review and evaluation of factors limiting Northern Goshawk populations. *Stud. Avian Biol.* 31:260–273.
- Rickman, T.H., B.E. Jones, D.R. Cluck, D.J. Richter, and K.W. Tate. 2005. Night roost habitat of radio tagged Northern Goshawks on Lassen National Forest, California. *J. Wildl. Manage.* 69:1737–1742.
- Roberson, A.M., D.E. Andersen, and P.L. Kennedy. 2005. Do breeding phase and detection distance influence the effective area surveyed for Northern Goshawks? *J. Wildl. Manage.* 69:1240–1250.
- Roberts, A.-M. 1997. Food habits of Northern Goshawks in the Queen Charlotte Islands and in the Kispiox Forest District 1996. B.C. Min. Environ., Lands and Parks, Smithers, BC. Unpublished report.
- Rohner, C. and F.I. Doyle. 1992. Food-stressed Great Horned Owl kills adult goshawk: exceptional observation or community process? *J. Raptor Res.* 26:261–263.
- Rutz, C., R.G. Bijlsma, M. Marquiss, and R.E. Kenward. 2006. Population limitation in the Northern Goshawk in Europe: a review with case studies. *Stud. Avian Biol.* 31:158–197.
- Salafsky, S.R. 2004. Covariation between prey abundance and Northern Goshawk fecundity on the Kaibab Plateau, Arizona. M.Sc. thesis. Colorado State Univ., Fort Collins, CO.
- Schnell, J.H. 1958. Nesting behavior and food habits of goshawks in the Sierra Nevada of California. *Condor* 60:377–403.
- Sibley, D.A. 2000. The Sibley guide to birds. National Audubon Society. Alfred A. Knopf, Inc., New York, NY.
- Smith, J.R., G. Sutherland, and D. O'Brien. 2007. Northern Goshawk (*Accipiter gentilis laingi*) habitat and territory models – draft. Modelling methodology and implementation and scenario results for coastal British Columbia (excluding Vancouver Island). Cortex Consultants Inc., Victoria, BC. Unpublished report.
- Snyder, N.F.R., H.A. Snyder, J.L. Lincer, and R.T. Reynolds. 1973. Organochlorines, heavy metals, and the biology of North American *accipiters*. *BioScience* 23:300–305.

- Sonsthagen, S.A., R.L. Rodriguez, and C.M. White. 2006. Satellite telemetry of Northern Goshawks breeding in Utah – II. Annual habitats. *Stud. Avian Biol.* 31:252–259.
- Sonsthagen, S.A., S.L. Talbot, and C.M. White. 2004. Gene flow and genetic characterization of Northern Goshawks breeding in Utah. *Condor* 106:826–836.
- Speiser, R. and T. Bosakowski. 1984. History, status, and future management of Goshawk nesting in New Jersey. *Records N.J. Birds* 10:29–33.
- Squires, J.R. and P.L. Kennedy. 2006. Northern Goshawk ecology: an assessment of current knowledge and information needs for conservation and management. *Stud. Avian Biol.* 31:8–62.
- Squires, J.R. and R.T. Reynolds. 1997. Northern Goshawk (*Accipiter gentilis*). In A. Poole and F. Gill, eds. *Birds of North America*, No. 298. The Academy of Natural Sciences, Philadelphia, PA and Am. Ornithologists' Union, Washington, DC.
- Squires, J.R. and L.F. Ruggiero. 1995. Winter movements of adult Northern Goshawks that nested in southcentral Wyoming. *J. Wildl. Manage.* 60:170–177.
- Stephens, R.M. 2001. Migration, habitat use, and diet of Northern Goshawks (*Accipiter gentilis*) that winter in the Uinta Mountains, Utah. M.S. thesis. Univ. Wyoming, Laramie, WY.
- Talbot, S.L. 2006. Genetic characteristics of goshawks in northwest North America: testing subspecies and Pleistocene refugium hypotheses. Abstract, 4th N. Am. Ornithological Conference, Veracruz, Mexico.
- Talbot, S.L., J.R. Gust, G.K. Sage, and S.A. Sonsthagen. 2005. Preliminary investigations of genetic relationships among goshawks of Alaska and British Columbia. U.S. Geol. Survey, Anchorage, AK. Unpublished report.
- Taverner, P.A. 1940. Variation in the American Goshawk. *Condor* 42:157–160.
- Tewksbury, J.J., S.J. Hejl, and T.E. Martin. 1998. Breeding productivity does not decline with increasing fragmentation in a western landscape. *Ecology* 79:2890–2903.
- Titus, K., C.J. Flatten and R.E. Lowell. 1994. Northern Goshawk ecology and habitat relationships on the Tongass National Forest (goshawk nest sites, food habits, morphology, home range and habitat data). First annual progress report. U.S. Dep. Agric. For. Serv., Alaska Dep. Fish and Game, Juneau, AK. Contract 43-0109-3-0272. Unpublished report.
- _____. 1999. Goshawk ecology and habitat relationships on the Tongass National Forest. Alaska Dep. Fish and Game, Division of Wildlife Conservation, Douglas and Ketchikan, AK.
- Tornberg, R. and A. Colpaert. 2001. Survival, ranging, habitat choice and diet of the Northern Goshawk *Accipiter gentilis* during winter in Northern Finland. *Ibis* 143:41–50.

- Toyne, E.P. 1997. Nesting chronology of Northern Goshawks (*Accipiter gentilis*) in Wales: implications for forest management. *Forestry* 121:121–126.
- United States Fish and Wildlife Service (USFWS). 1997. Draft Queen Charlotte Goshawk status review. Anchorage, AK. Unpublished report.
- _____. 2007. Queen Charlotte Goshawk status review. Alaska Region, Juneau Fish and Wildlife Field Office, Juneau, AK. 173 pp. Unpublished report.
- Ward, J.M. and P.L. Kennedy. 1996. Effects of supplemental food on size and survival of juvenile Northern Goshawks. *Auk* 113:200–208.
- Watson, J.W., D.W. Hays, and S.P. Finn. 1998. Prey of breeding Northern Goshawks in Washington. *J. Raptor Res.* 32:297–305.
- Whaley, W.H. and C.M. White. 1994. Trends in geographic variation of Cooper's Hawk and Northern Goshawk in North America: a multivariate analysis. *Western Foundation of Vertebrate Zool.* 5:161–209.
- Widén, P. 1997. How, and why, is the goshawk (*Accipiter gentilis*) affected by modern forest management in Fennoscandia? *J. Raptor Res.* 31:107–113.
- Wiens, J.D. 2004. Post-fledging survival and natal dispersal of Northern Goshawks in Arizona. M.Sc. thesis. Colorado State Univ., Fort Collins, CO.
- Wiens, J.D., B.R. Noon, and R.T. Reynolds. 2006. Post-fledging survival of Northern Goshawks: the importance of prey abundance, weather, and dispersal. *Ecol. Appl.* 16:406–418.
- Wiens, J.D. and R.T. Reynolds. 2005. Is fledging success a reliable index of fitness in Northern Goshawks? *J. Raptor Res.* 39:210–221.
- Wiens, J.D., R.T. Reynolds, and B.R. Noon. 2006. Juvenile movement and natal dispersal of Northern Goshawks in Arizona. *Condor* 108:253–269.
- Woodbridge, B. and P.J. Detrich. 1994. Territory occupancy and habitat patch size of Northern Goshawks in the southern Cascades of California. *Stud. Avian Biol.* 16:83–87.
- Zwicker, F.C. 1992. Blue Grouse. In A. Poole, P. Settenheim, and F. Gill, eds. *The Birds of North America*, No. 15. The Academy of Natural Sciences and the American Ornithologists Union, Washington, DC.

Personal Communications and Observations

Bloxton, T. 2005.

Brockman, Steve. October 2005. U.S. Fish and Wildlife Service, Juneau, AK.

Buelow, Markus. February 2005. Falconer, Vancouver Island, B.C.

Desimone, Steve. Washington Department of Fish and Wildlife, Olympia, WA. January

Doyle, Frank. September 2003. Wildlife Dynamics Consulting, Telkwa, BC.

Finn, Sean. January 2005. U.S. Geological Survey, Boise, ID.

McClaren, Erica. Ecosystems Biologist (Northern Goshawk *Accipiter gentilis laingi* Recovery Team Chair).

Reynolds, Richard. August 2006 and October 2005. U.S. Forest Service, Fort Collins, CO.

Schwantje, Helen. March 2005. B.C. Ministry of Environment, Victoria, BC.

Talbot, Sandra. November 2005. U.S. Geological Survey, Anchorage, AK.

Wijdeven, Berry. September 2004. Ministry of Environment, Queen Charlotte City, BC.

Wilson, Barb. November 2004. Cultural Projects Manager for Gwaii Haanas National Park.

GLOSSARY

Active nest: a nest where there is sufficient evidence that a breeding attempt has occurred within a given year. Sufficient evidence includes eggshell fragments at the base of a nest tree, an incubating adult or nestlings on a nest, or evidence that nestlings were present within a nest such as sufficient excrement below the nest tree.

Biogeoclimatic subzone: a climatic or zonal classification system that uses vegetation, soils, and topography to infer the regional climate of a geographic area. Biogeoclimatic subzones are delineated where different plant associations occur; this is the basic unit of this climatic classification system (<<http://www.for.gov.bc.ca/hre/becweb/system/how/climatic.html>>).

Biogeoclimatic variant: areas that are slightly drier, wetter, snowier, warmer, or colder than that considered typical for the subzone. These climatic differences result in corresponding differences in vegetation, soil, and ecosystem productivity, although the changes in the vegetation are not sufficient to define a new plant association. The differences in vegetation are evident as a distinct climax plant subassociation (<<http://www.for.gov.bc.ca/hre/becweb/system/how/climatic.html>>).

Breeding dispersal: the movement of adult birds from one breeding site to another between years (Greenwood 1980). For Northern Goshawks, this may include movement between alternative nest sites within a single nest area or between different nest areas.

Breeding home range: the area used by adult birds from courtship until young vacate natal areas (February through early September for *A. gentilis laingi*).

Core-use area: areas of an organism's larger home range where activities (such as breeding) are concentrated.

Critical habitat: the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species.

Ectoparasites: parasites that live on a host's outer surface.

Environmental stochasticity: fluctuating environmental conditions such as rainfall, snow levels, temperatures, etc.

Foraging area: the areas where adult and dispersing immature Northern Goshawks hunt. Foraging areas may or may not include nest trees and post-fledging areas and they make up the majority of an individual's home range (Reynolds *et al.* 1992).

Habitat: the resources and conditions present in an area that produce occupancy — including survival and reproduction — by an organism (Hall *et al.* 1997).

Habitat fragmentation: the isolation of parcels of habitat such that suitable habitat patches are separated from other suitable habitat patches by unsuitable habitat.

Habitat loss: a reduction in the amount of area that serves as habitat for a particular species.

Hard edges: the edge between two adjacent forest stands that differ in age and structural characteristics. For example, the edge between one stand that is <20 years and another stand that is >45 years. These types of edges are often created through human disturbances on the landscape rather than through natural processes.

Intra-specific competition: interactions between individuals of the same species for limited resources.

Inter-specific competition: interactions between individuals of different species for limited resources.

Introduced species (also known as an exotic species): is an *organism* that is not indigenous to a given place or area and instead has been accidentally or deliberately transported to this new location by *human* activity.

Natal dispersal: the process whereby individuals move from their natal area to where they first reproduce.

Nest areas: the component of a Northern Goshawk's home range that is occupied by one breeding pair during each breeding season and contains multiple alternative nest trees. Nest area size varies and depends on the topography and availability of suitable breeding habitat.

Non-colonial: individuals that nest singularly rather than in groups (colonies).

Occupancy rates: a nest area of *A. gentilis laingi* is considered to be occupied if at least one adult or fledgling is detected. This metric is calculated using the number of nest areas with active nests divided by the total number of nest areas assessed for occupancy.

Panmictic: a population where all individuals are potential breeding partners (i.e., there are no group structures or mating restrictions in the population).

Partial foraging habitat: a segment or part of a breeding pair's foraging habitat.

Persecution: persistent harassment or mistreatment by humans.

Post-fledging (family) area: the area around nest trees that fledglings use to retrieve food and learn to fly before they become independent of adults and leave their natal areas (Reynolds *et al.* 1992; Kennedy *et al.* 1994).

Residence: defined in the *Species at Risk Act* as a dwelling-place, such as a den, nest, or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding, or hibernating.

Recruitment: the process whereby immature individuals enter into the breeding population.

Sedentary: non-migratory.

Seral stage: stages of forests as they age and progress through a number of successional structural forms.

Socially monogamous: when individuals pair with the same mate for at least one breeding season.

Spatially explicit population model: a model that links vital rates (survival, productivity, lifespan, dispersal) for species to landscape-level habitat characteristics.

Subspecies: a taxonomic subdivision of a species that includes a group of organisms whose behaviour and/or genetically encoded morphological and physiological characteristics differ from those of other members of their species. Members of different subspecies of the same species are potentially capable of breeding with each other and of producing fertile offspring but there are often geographic, behavioural, or other such “barriers” that minimize interbreeding.

Synchronous breeder: individuals of a species that initiate breeding at approximately the same time within the breeding season.

Territory model: a model that uses information from nesting and foraging habitat suitability models to predict where sufficient nesting and foraging habitat is present to support a breeding pair of *A. gentilis laingi* (i.e., territory). This model also uses information about the spacing patterns between adjacent pairs of *A. gentilis laingi* to predict how many breeding pairs could be supported within a given landscape.

Verification: the process of collecting data during site visits to check whether predictions from habitat suitability models, and variables used as inputs for models, are valid.

Winter home range: the area used by birds during the non-breeding season (September through February for *A. gentilis laingi*).

APPENDIX 1. Existing approaches and measures available to protect habitat for *A. gentilis laingi*

Within Table A1, the recovery team has outlined current legislation in Canada, and the mechanisms within the legislation, that may provide habitat protection for *A. gentilis laingi* either through targeted or incidental habitat protection. As well, the recovery team has estimated the scale of habitat protection that may be enabled through each legislation/mechanism. Once critical habitat has been delineated for *A. gentilis laingi*, the recovery team will have a clearer understanding of how useful these tools will be for protecting their critical habitat.

Table A1. Legislation and mechanisms available to protect *A. gentilis laingi* and their habitats.

Legislation	Mechanism(s)	Responsible agency	Scale of habitat protection for <i>A. gentilis laingi</i>	Implementation date and status
<i>Wildlife Act</i> http://www.qp.gov.bc.ca/statreg/stat/W/96488_01.htm • Section 34	Protection	MOE — provincial ^a	Individual, eggs, active nests	1996
<i>Wildlife Amendment Act</i> ^b http://www.legis.gov.bc.ca/37th5th/1st_read/gov51-1.htm • Section 5	Residences	MOE – provincial	Individual, eggs, nests	2006 – ongoing development
<i>Forest and Range Practices Act (FRPA)</i> http://www.for.gov.bc.ca/tasb/legsregs/frpa/frpa/frpatoc.htm • FRPA S. 3	Forest Stewardship Plans	MOFR – provincial ^c	Nest trees, post-fledging area, foraging habitat	Dec. 31, 2006 – ongoing development
• FRPA S.5(b)(i)(ii)	Objectives set by government and other FRPA objectives	MOFR – provincial MOE – provincial MAL – provincial ^d	Nest trees, post-fledging area, foraging habitat	Dec. 31, 2006 – ongoing development
• FRPA S. 180, S. 181 and S. 182	Grandparented ungulate winter ranges, wildlife habitat areas, general wildlife measures	MOE – provincial	Nest trees, post-fledging area, foraging habitat	Carry-over from Forest Practices Code (FPC)

Legislation	Mechanism(s)	Responsible agency	Scale of habitat protection for <i>A. gentilis laingi</i>	Implementation date and status
Forest Planning and Practices Regulation (FPPR) http://www.for.gov.bc.ca/tasb/legsregs/frpa/frparegs/forplanprac/fppr.htm • FPPR S. 7(1)(a)(b)	Objectives set by government for wildlife Amount, distribution and attributes for species in S. 7(2) Notices	MOE – provincial	Nest trees, post-fledging area	Notice provided by Forest District – December 31, 2005
• FPPR S. 8	Objectives set by government for water, fish, wildlife, and biodiversity within riparian areas - Riparian Reserve Zone - Riparian Management Zone	MOFR – provincial	Partial foraging habitat^f	Carry-over from FPC
• FPPR S. 9	Objectives set by government for wildlife and biodiversity – landscape level - Harvest patterns should mimic natural disturbance regimes - Cutblock size	MOFR – provincial	Partial-foraging habitat	Carry-over from FPC
• FPPR S. 9.1	Objectives set by government for wildlife and biodiversity – stand level Wildlife tree patches	MOFR-provincial	Partial-foraging habitat	Carry-over from FPC

Legislation	Mechanism(s)	Responsible agency	Scale of habitat protection for <i>A. gentilis laingi</i>	Implementation date and status
<i>Government Actions Regulation (GAR)</i> http://www.for.gov.bc.ca/tasb/legsregs/frpa/frparegs/govact/gar.htm <i>GAR S. 9</i>	General wildlife measures	MOE – provincial	Nest trees, post-fledging area, partial-foraging habitat	Carry-over from FPC
<i>GAR S. 10</i>	- Wildlife habitat area for <i>A. gentilis laingi</i> - Wildlife habitat area for other category of species at risk	MOE – provincial	Nest trees, post-fledging area, partial-foraging habitat Nest trees, partial-foraging habitat	Carry-over from FPC
<i>GAR S. 11</i>	Wildlife habitat feature	MOE – provincial	Nest trees	Being developed – 2006
<i>GAR S. 12</i>	Ungulate winter ranges	MOE – provincial	Nest trees, post-fledging area, partial-foraging habitat	Carry-over from FPC
<i>Land Use Objectives Regulation</i> <i>Land Amendment Act</i> http://www.legis.gov.bc.ca/37th4th/3rd_read/gov46-3.htm <i>S. 93.8 Old-growth Order</i> http://srmwww.gov.bc.ca/rmd/oldgrowth/index.htm	- Land use plans - Land and resource management plans - Order establishing provincial non-spatial old-growth objectives	MAL – provincial	Nest trees, post-fledging area, foraging habitat Nest trees, post-fledging area, partial-foraging habitat	February 1, 2006 June 30, 2004
<i>Park Act</i> http://www.qp.gov.bc.ca/statreg/stat/P/96344_01.htm	Management plans	MOE – provincial	Nest trees, post-fledging area, foraging habitat	August 1, 1990

Legislation	Mechanism(s)	Responsible agency	Scale of habitat protection for <i>A. gentilis laingi</i>	Implementation date and status
<i>Ecological Reserve Act</i> < http://www.qp.gov.bc.ca/statreg/stat/E/96103_01.htm >	Management plans	MOE – provincial	Nest trees, post-fledging area, foraging habitat	1996
Species at Risk Act (SARA) < http://lois.justice.gc.ca/en/S-15.3/index.html > • SARA S. 32 • SARA S. 33 • SARA S. 57–58	• Individual harm • Residence • Action plan ◦ Safety nets for non-federal lands	Parks Canada, Fisheries and Oceans Canada, Environment Canada (Canadian Wildlife Service) - Federal	Individuals, eggs Nest Nest trees, post-fledging area, partial-foraging habitat	• June 2004 • Being developed by MOE and federal government • After identified by recovery team and published in Canada Gazette
<i>Canada National Parks Act</i> < http://laws.justice.gc.ca/en/n-14.01/251405.html >	National Parks and Heritage sites	Parks Canada – federal	Individuals, eggs, nest trees, post-fledging area, foraging habitat	October 20, 2000
<i>Private Managed Forest Land Act</i> < http://www.legis.gov.bc.ca/37th4th/3rd_read/gov88-3.htm >	Critical wildlife habitat	Private managed forest landholders	Nest trees, post-fledging area	August 2004
<i>Canadian Environmental Assessment Act</i> (CEAA) < http://lois.justice.gc.ca/en/C-15.2/225560.html >	Environmental assessments of projects and listed activities (Inclusion List Regulations)	Canadian Environmental Assessment Agency and other responsible authorities under CEAA	Individual, eggs, nest trees, post-fledging area partial-foraging habitat	January 19, 1995

Note: Several other mechanisms may assist in protecting habitat for *A. gentilis laingi* that do not include legislation. These can be extremely important and include forest certification programs (<<http://www.for.gov.bc.ca/het/certification>>), professional responsibilities to manage for species at risk (<http://www.abcfp.ca/regulating_the_profession/documents/guideline-species-at-risk.pdf>) under the B.C. *College of Applied Biology Act* (<<http://www.for.gov.bc.ca/tasb/legsregs/biology/caba.htm>>) and the B.C. *Professional Forester's Act* (<http://www.qp.gov.bc.ca/statreg/stat/F/03019_01.htm>), as well as shared stewardship and best management practices.

^a British Columbia Ministry of Environment; ^b The *Wildlife Amendment Act* will eventually be amalgamated with the *Wildlife Act*; ^c British Columbia Ministry of Forests; ^d British Columbia Ministry of Agriculture and Lands; ^e Partial foraging habitat indicates that only portions of breeding pair's foraging areas will be protected. The amount and distribution are variable and determined by the party who applies the mechanism.

Research Article

Black Bears Select Large Woody Structures for Dens in Southeast Alaska

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ABSTRACT Timber interests target coastal temperate rainforests, and within them stands composed of large trees potentially selected by American black bears (*Ursus americanus*) for denning. We identified the location of 75 black bear dens (used ≥ 14 days) in an intensively logged area on Prince of Wales Island, Alaska, USA. We ground-visited a subset ($n = 43$) of these sites to measure the diameter of living trees and woody structures used by black bears for denning. We contrasted dens with random trees available in the study area in a series of models to characterize black bear den selection. All but 1 of 43 ground-visited dens were located within woody structures, and all but 2 of these structures were >1 m diameter at breast height (dbh). We built resource selection functions (RSFs) to investigate black bear den selection across a range of spatial scales, though estimated selection was generally scale invariant. Black bears strongly selected large-diameter woody structures (dead or alive) as dens at the home-range scale, with the estimated relative strength of selection (RSS) for a 2-m-diameter tree approximately 166 times that of a 1-m-diameter tree. The estimated RSS of logged forest was unexpectedly greater (2.75 times) than that of the remaining commercially valuable old-growth forest. Selection for den structures within stumps in previously logged stands suggests features of the woody structure may be of greater importance to black bears selecting dens than attributes of the surrounding forest. There was no observed correlation between bear den selection and second-growth age, indicating that stumps may persist as suitable dens well after logging. Because denning is an important part of their life history and the denning structures used by black bears on Prince of Wales Island will eventually decay, retaining habitat value for bears in areas intensively managed for timber harvest requires strategies to recruit very large, old trees throughout the landscape. © 2021 The Wildlife Society.

KEY WORDS black bear, denning, logging, Prince of Wales Island, resource selection, Southeast Alaska, *Ursus americanus*.

Temperate forests of North America support a host of vertebrate species by providing food (Hagar 2007), nest (Bunnell et al. 2002) and den sites (Delheimer et al. 2019), and protection from predators (Kunkel and Pletscher 2000), thermal extremes (Bose et al. 2018), and snow (Kirchoff and Schoen 1987). Within these forests, cavity-nesting birds and denning mammals may be especially reliant on larger trees and snags (Stevenson et al. 2006, Delheimer et al. 2019). These large trees have historically been the target of the logging industry (Kennedy and Spies 2004, Albert and Schoen 2013) because of their commercial value. In Southeast Alaska, USA, this has led to a decrease in large trees and potentially the wildlife habitat they provide (Albert and Schoen 2013).

The suitability of woody structures (both living and dead trees) as nest or den sites is dependent on the rate of their

recruitment (Barry et al. 2017), which may be limited in coastal temperate rainforests by extensive logging (Delheimer et al. 2019). Live trees, snags, and down logs used as nests and dens by a number of forest birds (Mahon et al. 2008) and mammals (Barry et al. 2017) are more prevalent in unlogged forests generally >200 years old (Gerzon et al. 2011, Hennon and Mulvey 2014). The suitability of these woody structures for wildlife use can also be dependent on their rate of decay (Edworthy and Martin 2013), which may depend on tree species (Parish et al. 2010), whether the structure is living or dead (Edworthy and Martin 2014), and whether standing or down (Vanderwel et al. 2006).

American black bears (*Ursus americanus*) may den in particularly large live and dead trees (Bull et al. 2000, Davis et al. 2012). Suitable den and resting sites provided by live and dead trees may be important for the survival of bears (Johnson and Pelton 1981, Linnell et al. 2000). In moist environments, dens excavated in soil may flood, resulting in cub mortality (Alt 1984), and in higher-latitude forests,

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adequate denning trees may afford bears thermal protection (Davis et al. 2012). Denning is prolonged in higher latitudes in response to cold temperatures and limited food resources (Smith et al. 1994), which indicates the potential value of adequate dens to bear condition and survival in these climates.

Black bears on Prince of Wales Island (POW) in Alaska contend with other management-related factors potentially affecting their population. Hunters have killed as many as 480 black bears in a year in Alaska Department of Fish and Game (ADFG) Game Management Unit 2, which includes POW and surrounding islands (9,074 km²), with a mean of 231 ± 110 (SD) in 1980–2019 (ADFG 2002, 2011, 2020). Large-scale logging commenced in the late 1950s and resulted in present-day stem-excluded forests (Alaback et al. 2013), which may lack forage plants used by bears (Davis et al. 2012, Hertel et al. 2016). Salmon relied on by bears seasonally may be negatively influenced by logging (Nehlsen et al. 1991) and climate change (Shanley et al. 2015). Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) fawns preyed on by black bears (Gilbert et al. 2017) fluctuate in abundance on POW and are also potentially affected by logging activities. These factors may interact with the availability of suitable den structures to influence black bear abundance.

We investigated selection of woody structures as dens by black bears on POW in Southeast Alaska using resource selection functions (RSFs). Specifically, we tested 5 predictions related to bear selection of woody structures in old- and second-growth forests.

1. Black bears will select large-diameter woody structures for denning, with a steep selection gradient between smaller and very large structures as measured by diameter at breast height (dbh model).
2. Bears will select old-growth forests for denning over logged second growth because of potential presence of more suitable woody structures (old-growth model).
3. Within second-growth forests, bears will select younger stands because the stumps left behind in older second growth decay and become unsuitable for use as dens through time (second-growth age model).
4. Within old-growth forests, areas bears will select for denning will have greater timber volume (m³/ha), an indicator of timber value, and this may indicate the potential for conflict between logging and bear conservation interests because logging in Southeast Alaska has historically targeted higher volume forests (Albert and Schoen 2013; timber volume model).
5. The relative probability of bear den presence can be predicted and mapped across the study area to help determine the location of future logging activities (predictive map model).

STUDY AREA

We conducted the study during 2009–2012 on northcentral POW (6,670 km²; Fig. 1), one of the myriad islands that comprise the Alexander Archipelago in Alaska. The maritime climate was characterized by cool summer (Jun–Aug;

<18°C) and mild winter (Nov–Mar; >0°C) mean temperatures. Precipitation usually fell as rain throughout the year, with annual mean precipitation approximately 2.5 m, but also fell as snow in winter (annual mean snowfall = 0.57 m; Western Regional Climate Center 2019), particularly at higher elevations, which range to 1,186 m. Terrain at high elevations is generally steep and rugged post-glacial ridges and valleys with some flat flood plains and uplifted marine terraces nearer sea level.

Conifer forests were prevalent on POW interspersed with fens (mostly low-angle, poorly drained soils), shrubs (particularly on steep slopes that experience recurring landslides or avalanches), and alpine tundra at higher elevations. Forests were dominated by Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), Alaska yellow cedar (*Chamaecyparis nootkatensis*), and western red cedar (*Thuja plicata*). The plant understory community was a mix of species including blueberry (*Vaccinium* spp.), salal (*Gaultheria shallon*), devil's club (*Oplopanax horridus*), salmonberry (*Rubus spectabilis*), and others (Alaback et al. 2013). Black bears on the island co-occurred with resident populations of Sitka black-tailed deer and wolves (*Canis lupus*).

Industrial scale logging on POW began in the 1950s (Albert and Schoen 2013) and continues to the present. Forests in Southeast Alaska have a limited major disturbance history, and prior to logging were virtually all in old-growth condition. Clearcut logging has converted 36% of the commercially valuable forest in the study area to younger successional stages (U.S. Forest Service [USFS] 2019a). Commercial forest lands within the study area represented a mosaic of stand ages including recent clearcuts (<30 yrs old) with a dense shrub understory and open but developing tree canopy, older clearcuts (≥30 yrs old) with a dense, even-aged tree canopy and little understory, and old-growth forest with canopy gaps and complex stand structure (Alaback et al. 2013). Most of the land (96%) in the study area was managed by the USFS Tongass National Forest, with the remaining 3.7% managed by the State of Alaska (Division of Forestry) and private owners.

METHODS

We captured, immobilized, and radio-collared bears May–October each year from 2009–2012 according to protocols approved by the Alaska Department of Fish and Game, Division of Wildlife Conservation Institutional Animal Care and Use Committee (number 09-17). We used bucket snares consisting of a single spring-activated Aldrich foot snare inside a 18.9-L plastic bucket (M-15 model, Snare Shop, Lidderdale, Iowa, USA) affixed to trees at a height of approximately 2 m because we intended to capture bears by a front paw. We fitted bears with Telonics global positioning system (GPS; model TGW-3600, 3700, or 3790; Telonics, Mesa, AZ, USA) or Telonics very high frequency (VHF) collars. The GPS-collars were set to attempt GPS fixes every 30 minutes except in winter when fixes were attempted every 24 hours; collars were

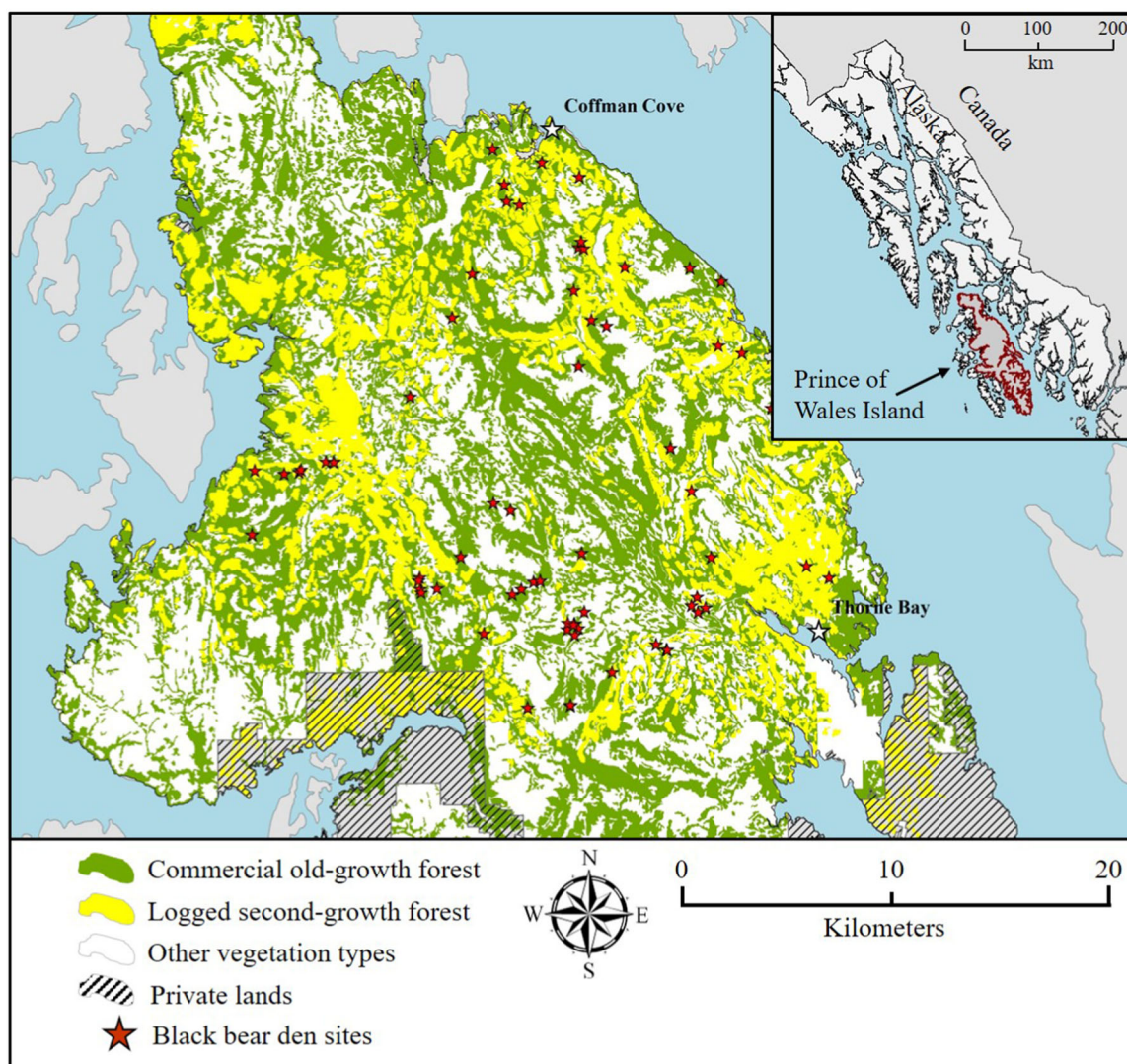


Figure 1. Black bear den selection study area on Prince of Wales Island, Alaska, USA, 2009–2012, showing location of dens and logged and unlogged commercial forest.

programmed to drop off animals generally after a 2-year deployment.

We located dens included for analysis by tracking the VHF-collar signal to the den ($n=43$) or solely by inference from GPS fixes ($n=33$) during 2009–2012. Although we chose the subset of dens visited on the ground opportunistically, all 95% confidence intervals on differences between landscape attribute means for visited and unvisited dens included zero.

Some GPS-collars on bears did collect locations sporadically during winter, but the sparse schedule coupled with poor GPS reception from within den structures resulted in some of the GPS-collars collecting no successful GPS locations. For this reason, we also inspected temperature and activity readings from collars and inferred the den location from the cluster of GPS locations collected prior to denning; we inferred the timing of denning by increased temperatures and decreased activity recorded by the collar. Conversely, increased activity and decreased temperature indicated the timing of emergence from the den. We

assumed dens used for <14 days may not be suitable, and we excluded these from analysis, although some of these bears may have been displaced when we approached their den. Preliminary investigation did not reveal compelling evidence for differences in selection patterns between male and female bears. Thus, we pooled data from males and female bears in all models.

For the subset of dens visited on the ground, we measured the diameter at breast height (dbh; 1.37 m from the ground) of each woody structure (i.e., any live tree, down log, stump) in which dens occurred. When we located a den within a down log, we measured dbh at 1.37 m from the juncture of the roots and trunk. We also noted the tree species (unless decomposition made identification impossible) and where the den was situated—in the trunk of a living tree, within a fallen log, or under the trunk (within the root structure) of a living tree or logged stump.

We generated an initial pool of available points sampled regularly (density = $300/\text{km}^2$) within a $1,505\text{-km}^2$ study area polygon constructed using the 95% kernel density estimate

built on all telemetry locations collected from GPS-collared bears using R package *adehabitatHR* (Calenge 2006) function *kernelUD* using the least squares cross-validation bandwidth (LSCV) estimator. This initial sample of available points was far greater the number of dens, but we later subset this pool of points according to 1) spatial extent of inference of each model, and 2) the number of available points at which model coefficients stabilized (Northrup et al. 2013). We then clipped the study area to the marine shoreline and to public lands where landscape covariates were mapped. Nearly all covariates included in models were mapped landscape attributes of den and available locations (Table 1) measured using the raster package (Hijmans 2020) in R (R Core Team 2020). The exception was dbh, which we measured for all ground-visited dens, and contrasted with a set of trees available for bear denning obtained from 2 forest inventory databases (Caouette and DeGayner 2008, Reynolds 2019). We then constrained the full set of available points for use in each model depending on the specific hypothesis and model (Table 2). The pool of available points used for the dbh model varied from other models because tree diameter was not available as a continuous layer across the study area but instead existed as tree measurements gathered from georeferenced forest inventory plot information.

To investigate den selection at varying spatial scales, we further subset the pool of available points for each model to the annual home ranges of bears and to buffers created at 500-, 1,000-, and 2,000-m radii around each den (Fig. S1, available online in Supporting Information). We generated home ranges for each bear using a set of continuous-time movement models via the R *ctmm* package (Calabrese et al. 2016) and chose the home range with the greatest support via Akaike's Information Criterion for small sample sizes (AIC_c; Burnham and Anderson 2002) score. We did not have adequate telemetry data to estimate annual home ranges for all bears, so when we collected less than a full year

of data for a bear associated with a given den, we instead used another bear's annual home range that encompassed the den. When the home range of >1 bear encompassed such dens, we used the home range with area closest to the median in the interest of using the most appropriate spatial scale. The low density of forest inventory data used for the dbh model did not allow analysis at scales smaller than the home range.

The existence of used locations amongst the sample of available points (i.e., contamination) has been cited as a cause for bias in model coefficient estimates (Keating and Cherry 2004). Johnson et al. (2006), however, reported that contamination rates must be extreme to affect coefficient estimates, and the density of black bears in Southeast Alaska and adjacent regions (0.13–1.51/km²; Peacock et al. 2011, Welfelt et al. 2019) suggest low levels of contamination.

We developed a pool of candidate models for each of the first 4 black bear den selection models and included in each candidate model a target covariate of interest (Table 1) we were interested in relating to the relative probability of den presence. Along with this target covariate we included all combinations of a set of ecologically plausible supporting covariates: elevation (m), slope (°), solar radiation (WH/m²), topographic position index, terrain ruggedness, and road density (km/km²; Table 1). These covariates had been used by previous authors to model bear den selection (Gaines 2003, Immel et al. 2013, Pigeon et al. 2014) and we used them to provide a realistic setting within which to accurately estimate the main covariate of interest. For each model, we then used model averaging (Burnham and Anderson 2002) across all candidate models to obtain final model coefficients. We also built a fifth, predictive model not focused on a specific relationship but instead on building an accurate map of relative denning probability across the study area. We developed this predictive map model in a similar fashion but used a subset of the supporting covariates (Table 1) used in the first 4 models and a subset from

Table 1. Descriptions of covariates and their derivation for black bear den selection models, Prince of Wales Island, Alaska, USA, 2009–2012. We included in models target covariates for which we were interested in estimating a specific relationship with bear denning probability, and supporting covariates used to obtain realistic models.

Covariate	Description
Target covariates	
Diameter of woody structure (dbh, m)	Diameter of woody structure used as den, measured at the site. We obtained the available sample from forest inventory plot data (Caouette and DeGayner 2008; Reynolds 2019)
Old-growth forest	All commercially productive (timber volume >46.6 m ³ /ha) forest at the time of study (categorical) (USFS 2019a)
Age of second-growth forest	Years since logging occurred (USFS 2019a)
Timber volume (m ³ /ha)	Timber volume as estimated using forest plot data and light detection and ranging (LiDAR) forest structure data (Reynolds 2019)
Supporting covariates	
Elevation (m)	Elevation obtained from Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM)
Slope (°)	Slope derived from SRTM-DEM elevation
Solar radiation (watt-hour/m ²)	Solar radiation on 1 Apr 2012 calculated using the solar radiation tool in ArcGIS 10.5.1 (Esri, Redlands, CA, USA)
Topographic position index (TPI)	Topographic position index calculated from SRTM-DEM using focal function in the R raster package (Hijmans 2020)
Ruggedness (VRM)	Ruggedness calculated in 90-m moving windows from SRTM-DEM per the method of Sappington et al. (2007)
Road density (km/km ²)	Density of roads (USFS 2019c) in a 200-m circular radius calculated using the kernel density tool in ArcGIS 10.5.1

Table 2. Summary of black bear den selection models on Prince of Wales Island, Alaska, USA, 2009–2012. We used model averaging to construct each final model within a specific extent of inference to estimate a target coefficient (β) of interest, upper (UCL) and lower (LCL) confidence limits, and cross-validation performance via mean Spearman's rho across 100 cross-validation trials. We used discrete choice models for all but the predictive map model, for which we constructed a generalized linear model (GLM).

Model name	Covariate of interest	Extent	Number of dens	β	LCL	UCL	Spearman's rho	
							$\bar{r}$	SD
Dbh	Dbh (m)	Old-growth forest	43	1.71	1.55	1.87	0.68	0.04
Old growth	Old-growth land cover class	Study area	75	−1.01	−1.54	−0.47	0.83	0.04
Second-growth age	Years since timber harvest	Second-growth forest	39	0.17	−0.23	0.58	0.18	0.11
Timber volume	Timber volume (m ³ /ha)	Old-growth forest	38	0.36	0.09	0.63	0.65	0.09
Predictive map ^a	NA	Study area	75	NA	NA	NA	0.85	0.06

^a No specific covariate of interest was targeted in the predictive map model so some columns are not applicable (NA).

a pool of LiDAR-derived forest structure metrics, the selection of which we detail below. We standardized all continuous covariates. We used the estimated coefficient of the covariate of interest to calculate relative strength of selection (RSS; Avgar et al. 2017) as $\exp(\beta)$. We constructed 5 models (Table 2):

1. In the dbh model, we estimated RSS by denning bears for woody structures relative to their dbh by contrasting woody structures used as dens with trees available in old-growth forest obtained from 2 sets of forest inventory plot data. In these plot data, positional accuracy of individual trees was generally known to within ≤ 30 m (when only a plot center was georeferenced; Caouette and DeGayner 2008) or ≤ 3 m (when individual trees were georeferenced; Reynolds 2019), and so terrain covariates could be accurately assigned. For interpretation, we scaled RSS predictions from this model across a range of woody structure dbh to the RSS of a 1-m-diameter woody structure.
2. In the old-growth model, we tested whether the RSS for dens in old growth was greater than for second growth using an available sample randomly generated across logged and unlogged lands. Using the estimated coefficient for old growth, we presented the RSS value of old growth relative to second growth (the reference category).
3. We constructed the second-growth age model within logged forests to estimate the relationship between RSS and second-growth age.
4. We constructed the timber volume model within old-growth forest to estimate the relationship between RSS and mapped timber volume (m³/ha; Zhou and Hemstrom 2010, McGaughey 2018, Reynolds 2019) as a proxy for timber value. For the purpose of interpretation, we predicted den RSS across a range of timber volume scaled to the USFS minimum criteria for commercially valuable timber, 46.6 m³/ha (8,000 board feet/acre; USFS 2019b).
5. The purpose of the predictive map model was to map bear den RSS across the study area. Unlike the other 4 models, we did not focus on the effect of a specific covariate, we performed this analysis only at the study-area-scale to provide a map useful for landscape-level planning, and we used a somewhat different pool of covariates used (more details below).

For the first 4 models, we estimated RSS using discrete choice models (Cooper and Millsbaugh 1999, McDonald et al. 2006) matching a set of available locations with each den using the coxph function of the R survival package (Therneau 2021), allowing availability to vary among dens. We did not construct strata for individual bears because we identified only a single den location for 23 of 43 unique denning bears in this study. To ensure an adequate number of available points were matched with each den, we built models in which the number of matched available points varied from 10–300 and chose the number at which coefficient values and 95% confidence intervals stabilized, according to guidance presented by Northrup et al. (2013).

To obtain each of the first 4 final models, we performed model averaging across all candidate models, which included the target coefficient and all combinations of supporting coefficients ($n = 63$), averaging the coefficients of these models using AIC weights (Burnham and Anderson 2002) via the R package MuMIn (Bartoń 2020). Although there are many criteria potentially available for model selection and different nuances of model averaging, optimization was not important in this setting. Our desire was only to accurately estimate the coefficients of interest in each of the 4 discrete choice models. Therefore, in each set of models, we inspected the target coefficients of interest and ensured their stability across competing models regardless of the set of supporting covariates included in each model.

When the coefficient of interest in a model was informative (i.e., 95% CI not overlapping zero), we used it to calculate RSS given change of a single covariate as $\exp(\beta)$ while setting all other model covariates to their mean (continuous covariates) or zero (categorical covariates) using the predict.coxph function of the R survival package. These RSS values have previously often been referred to in the RSF literature as odds ratios, but Avgar et al. (2017) explain this is incorrect and we use their terminology here.

We cross-validated all models via a k -fold ($k = 5$) approach in which we compared observed and expected values via Spearman's rank correlation (Boyce et al. 2002, Johnson et al. 2006) and obtained the mean and standard deviation across 100 trials. This accounts for variability in Spearman's correlation across trials due to the random draw of training and validation sets in each k -fold trial.

For the predictive map model, we used a binomial generalized linear model (GLM) rather than the discrete choice models used in the other 4 models. This is because the study-area scale at which we constructed this model did not require spatially constraining the matched set of available points for each den, so we instead pooled all dens as the used set of points and contrasted these with a shared, available set of locations. Preliminary results also suggested greater predictive performance using the GLM approach. We chose the size of the available set of points for this model in the same fashion as the discrete choice models using the strategy of Northrup et al. (2013), plotting coefficient estimates across a range of increasing available sample sizes until they stabilized.

For the predictive map model, we built all candidate models from a pool of covariates including the supporting covariates used in the 4 discrete choice models, light detection and ranging (LiDAR) derived forest structure covariates, and a covariate representing unlogged areas of the study area. In the first 4 models, we did not include available LiDAR-derived forest structure covariates because these covariates generally were highly correlated with the model covariates of interest. Many potential LiDAR metrics were available, and we therefore took a series of steps to reduce the set of covariates considered, hence reducing the number of candidate models from >1,000 models to a more manageable set of models ($n=127$). We first removed 3 covariates that had been included in previous models (topographic position index, solar radiation, and road density) but were uninformative (95% CI overlapping zero) in univariate models. For the LiDAR metrics, we first built a univariate GLM with each metric, ranked these models via cross-validation performance (Spearman's rho), and rejected those metrics with cross-validation scores (Spearman's rho) <0.5. Using the remaining covariates, we then identified pairs with correlation ≥ 0.7 , and retained the covariate in each pair with the greater univariate GLM Spearman's rho value.

The LiDAR-derived covariates were available across unlogged areas and second-growth forests. In unlogged forests, these covariates characterize the structure of forests, and are of potential use predicting the relative probability of den presence. But in second-growth forests, these covariates are not likely useful for prediction because bears den in stumps not readily detected by LiDAR forest structure metrics. Therefore, to build predictive bear den models across unlogged areas and second-growth forests, we included LiDAR-derived covariates as interactions with a categorical variable representing unlogged areas. We included these terms as partial interaction terms that had continuous values within unlogged areas but did not affect model predictions in areas of second-growth forest. We used the coefficients obtained from model averaging to map RSS values across the study area. For interpretation, we binned the raw, continuous predictions into 5 quantiles (Morris et al. 2016) intended to correspond to relative value of habitat for black bear denning. Additionally, we produced a binned RSS map only applicable to unlogged areas of the landscape because

this extent is more applicable to planning future timber harvest. The main R scripts used in modeling are available online (Supporting Information S2).

RESULTS

We fitted 59 bears (32 males, 27 females) with GPS (22 males, 25 females) or VHF (10 males, 2 females) collars, which were deployed during 2009–2012. Bears wore collars for a median period of 426 days (range = 30–1,167). Fifteen radio-collared bears died during the study: 11 male and 1 female bear were legally killed by hunters, 1 male died as result of hunter wounding loss, and 2 males died of unknown causes. Bears used 75 dens with unique locations for a period ≥ 14 days, which we included in analysis (41 by males, 34 by females).

All but 1 black bear den was associated with a woody structure. Bears used live or dead western hemlock (47%), Sitka spruce (26%), and cedar (Alaska yellow cedar or western redcedar; 22%) as dens, the remainder of structures (7%) were too decayed to identify to species. The dbh of woody structures used as dens ranged from 0.77–2.30 m; 2 den structures had a dbh <1 m, and 3 den structures had a dbh >2.0 m (Fig. 2). Dens were located mostly at the base of woody structures surrounded by the root system (78%), the remainder (22%) were within the trunk. Dens were in a mix of lands mapped as commercially valuable old growth (39%), second growth (45%), and other forested lands (16%). The mean dbh ($\pm$ SD) of den structures within these land cover classes was 1.38 ± 0.13 , 1.37 ± 0.33 , and 1.41 ± 0.69 m, respectively. Dens located in second-growth forest were in stands logged between 15–53 years previously (1959–1997). The mean dbh of den structures (1.38 m) exceeded that of available forest inventory plot data (0.58 m), with the confidence interval not overlapping zero. The distribution of den and available dbh values overlapped but varied (Fig. 2).

When we increased discrete choice sets in size incrementally from 10–300 points per set, coefficients appeared to stabilize by 100 points per set (Fig. S3, available online in Supporting Information), so we used this choice set size in all 4 discrete choice models. The coefficients of interest in these 4 models were stable across the top ranked competing model subsets, and the model-averaged coefficient estimates were encompassed by the confidence intervals of nearly all candidate models (Fig. S4, available online in Supporting Information). This indicates that our findings were not sensitive to the model-selection approach used.

Model coefficients were largely scale invariant (Fig. S5, available online in Supporting Information). In 3 of the 4 discrete choice den selection models, there was little change in the coefficient of interest across scales. In the second-growth age model, the coefficient for age of logging decreased as the scale of the model increased, but the coefficient for second-growth age was not informative (95% CI surrounded zero) at any scale. Additionally, cross-validation scores (Spearman's rho) across model scales varied little but were highest or nearly so at the home-range scale (Table S6,

available online in Supporting Information). Because of the lack of scale dependency but relatively high cross-validation performance at the home-range scale, we largely focus on models obtained at this scale henceforth, except for the predictive map model, which we built only at the study-area scale for greatest utility to landscape-level forest management.

There was a substantial observed difference between the distribution of dbh between bear dens and forest inventory plot data (Fig. 2) that corresponded with a positive coefficient for dbh ($\beta = 1.71$, 95% CI = 1.55–1.87), indicating selection for large-diameter woody structures (Table 2). Black bear den RSS calculated from the dbh model across a range of tree diameters and scaled to a 1-m-diameter tree (Fig. 3), illustrates the rapid estimated increase in selection strength for larger diameter structures by bears. For instance, selection strength for a 2-m-diameter woody structure was estimated to be 166.4 times (95% CI = 153.2–197.7) that of a 1-m-diameter structure.

In the old-growth model, black bear den RSS for commercially valuable old growth was not greater than the second-growth forest (reference) class ($\beta = -1.01$, 95% CI = -1.5 to -0.48; Table 2). The converse was true and the RSS estimate ($1/\exp(\beta)$) for second growth was 2.75 times (95% CI = 1.62–4.66) that of commercial old-growth forest. In the second-growth age model, there was no evidence that black bear den RSS varied with stand age ($\beta = 0.17$, 95% CI = -0.23–0.58). From the timber volume model, black bear den RSS was positively associated with timber volume (Fig. 4); however, the coefficient for timber volume was moderate ($\beta = 0.36$, 95% CI = 0.09–0.63) relative to that for tree diameter from the dbh model (Table 2). The strength and sign of supporting covariates was generally stable across models (Appendix A).

In development of the predictive map model, filtering the LiDAR covariates based on their performance in univariate GLMs (Spearman's rho > 0.5), and subsequent paring of those covariates correlated at > 0.7, resulted in 3 LiDAR covariates being retained: 1) all LiDAR point returns above a height of 2 m, indicating the presence of trees; 2) canopy rumple, a measure of the roughness of the forest canopy; and 3) the L4 L-moment (Hosking 1990, McGaughey 2018) of the elevation of LiDAR returns, indicating the heaviness of tails in vegetation height relative to a normal distribution. In

practice, the L4 L-moment of LiDAR vegetation elevations highlights areas of coarse, variable tree canopy. The LiDAR metrics were included with 3 terrain variables (elevation, slope, and ruggedness) and a categorical covariate for non-harvested areas in the final model-averaged model used for prediction (Table A2). The coefficients for the 3 forest-structure metrics and for slope were positive, unlogged areas strongly negative, and elevation and ruggedness small, with confidence intervals surrounding zero. The predictive map model cross-validated with a mean Spearman's rho of 0.85 ± 0.06 (SD) across 100 trials. The model output resulted in a mosaic of areas across the landscape that fell into the top 20% quantile bin of black bear den RSS values (Fig. 5). The geographic information system raster tiff files of the top 20% quantile bin across the study area and constrained to unlogged areas are supplied in S7 and S8, respectively (available online in Supporting Information).

Models varied in their cross-validation performance from good (e.g., mean rho across 100 trials = 0.85 and 0.83 in the predictive map and old-growth models, respectively), to fair (mean rho = 0.68 and 0.65 in the dbh and timber volume models, respectively) to not acceptable (0.18 in the second-growth age model; Table 2).

DISCUSSION

Our results illustrate the importance of large woody structures for black bear dens in Southeast Alaska. Such large structures take long periods of time to grow but persist and are selected as dens while the trees are alive and for an unknown period after death by logging or natural causes. Allowing these trees to grow to the size of those selected by bears in this study (generally > 1 m) will promote their availability. Timber harvest rotations < 150 years will likely not permit recruitment of woody structures of a size selected by black bears as dens. This may be alleviated by retaining a certain proportion of trees in locations with favorable site conditions to grow. Once recruited, these woody structures appear to have a prolonged persistence as viable dens.

In second growth, cut stumps were the only structures in which we observed bears denning, and these stumps were of mean diameter not less than those trees, logs, and stumps used for dens in old growth. Albert and Schoen (2013) reported that logging in Southeast Alaska and on POW has

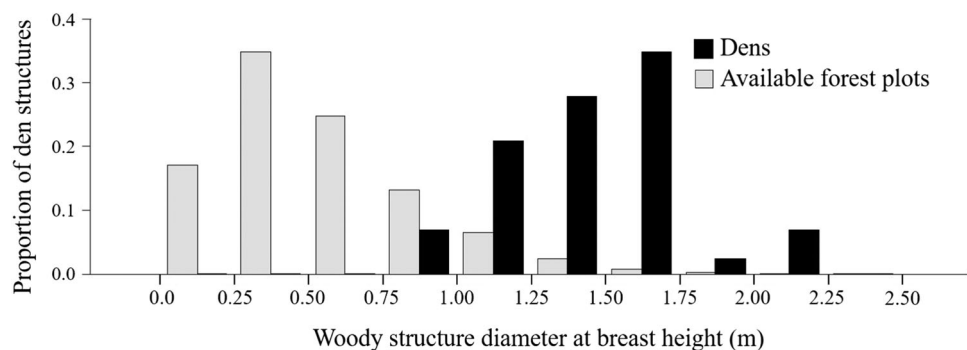


Figure 2. Distribution of tree diameters of used bear dens and random forest inventory plot trees in the black bear study area on Prince of Wales Island, Alaska, USA, 2009–2012.

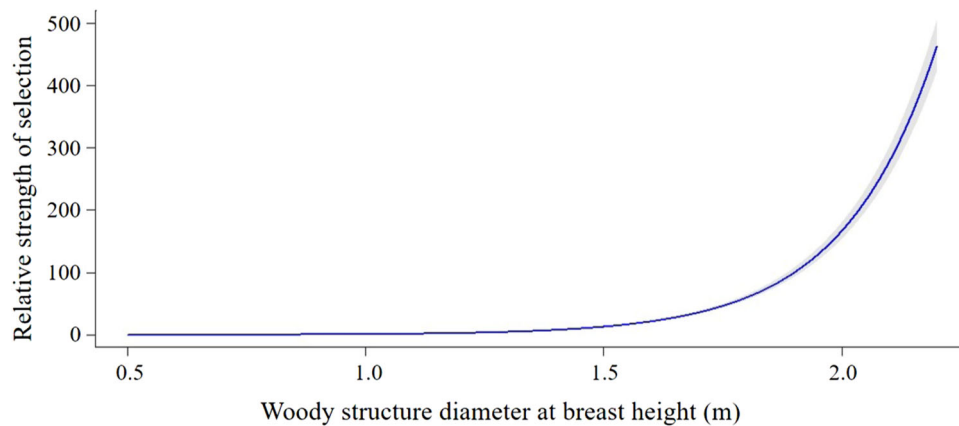


Figure 3. Predicted relative strength of selection (RSS) and 95% confidence interval for black bear dens versus diameter at breast height (m) of woody structures on Prince of Wales Island, Alaska, USA, 2009–2012. The RSS is scaled to that of a 1-m-diameter woody structure.

been disproportionately in stands with larger-diameter trees, and this may have resulted in many residual stumps of large size in second growth. Although we did not assess rates of den reuse by bears in this study, they can be high (Davis et al. 2012). The high selection for second growth by denning bears we observed may also be in part due to continued use of dens initially located within living trees before logging occurred.

We predicted that bear den RSS would be higher in stands of high timber volume. Although there was a correlation between timber volume and the relative probability of denning, it was moderate relative to the tie between woody structure diameter and denning, and the timber volume model cross-validated poorly. It appears that estimated timber volume does not accurately predict the presence of large woody structures used as bear dens. This is illustrated by the loose tie between the dbh of trees and the estimated timber volume observed in forest inventory plot data (Appendix B). Additional *post hoc* predictive GLM models run only in the extent of unlogged areas found that a model in which LiDAR forest structure covariates were excluded cross-validated nearly as well as a model in which both LiDAR metrics and terrain variables were used for

prediction (Spearman's rho 0.86 to 0.82, respectively). Our sample size in unlogged areas was limited to 37 dens, however, and we believe that a larger sample would show forest structural characteristics likely to have some influence on the availability of suitable dens. Small sample size also is reflected in the fair cross-validation results for the dbh model (Spearman's rho = 0.68), even though the dbh coefficient was strongly positive. Nonetheless, the strong cross-validation of our predictive map indicates its potential to assist forest management by identifying areas of higher bear den selection.

We did not analyze habitat at a fine scale in the immediate vicinity of dens, a scale shown to be influential in shaping brown bear (*Ursus arctos*) den selection (Pigeon et al. 2014); however, we have provided evidence at a larger scale that bears may be keying in on large woody structures that exist across forests of varying attributes, including in logged areas. Although it is clear bears selected large woody structures as dens in this study, it is not clear how limitations on the availability of these structures might affect their demographics, and perhaps other factors are more influential on black bear abundance. The strong selection for large woody structures where they are available, such as

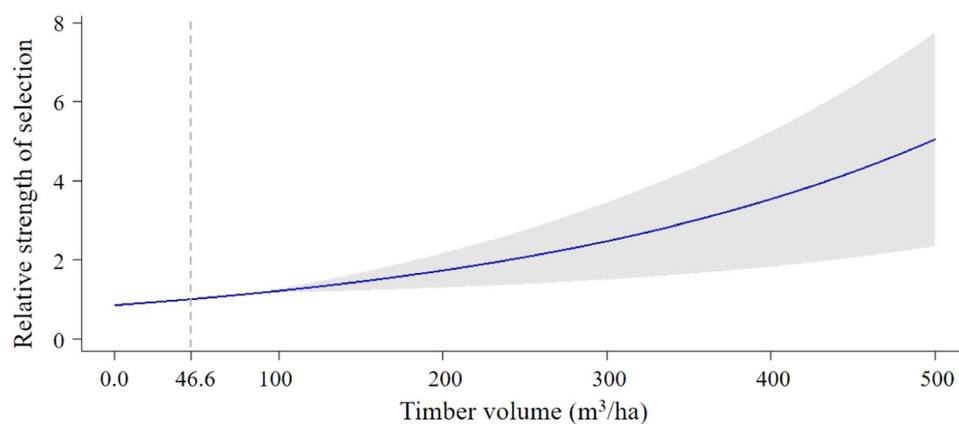


Figure 4. Predicted relative strength of selection (RSS) and 95% confidence interval for black bear dens versus mapped estimated timber volume (m^3/ha) on Prince of Wales Island, Alaska, USA, 2009–2012. The RSS is scaled to that predicted for the United States Forest Service minimum criterion for productive old-growth forest ($46.6 \text{ m}^3/\text{ha}$).

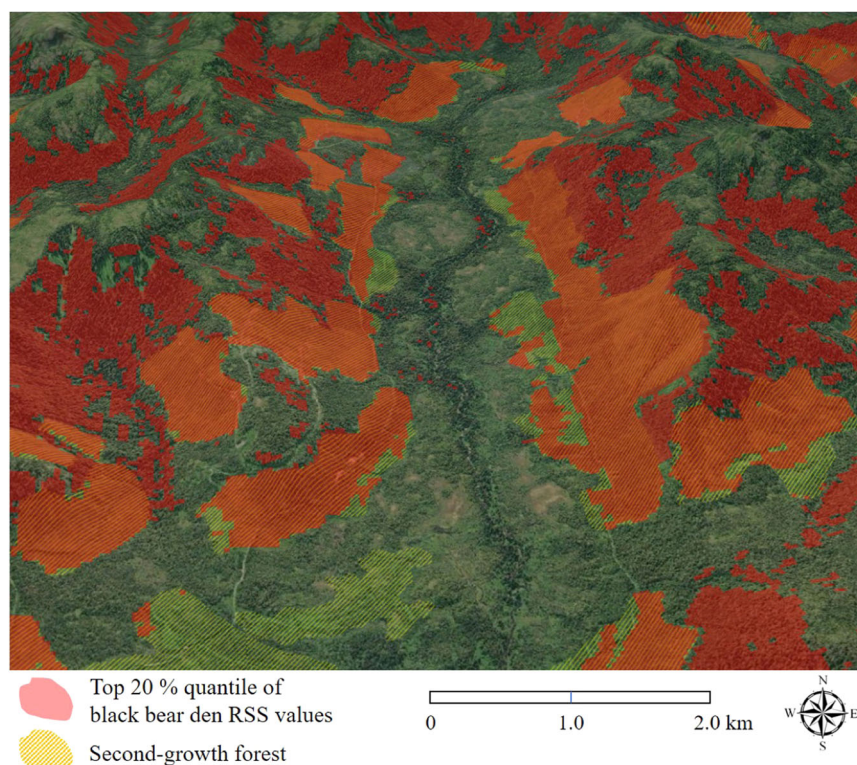


Figure 5. Top 20% quantile of black bear den relative strength of selection (RSS) predictions, depicted on a portion of the Staney Creek watershed, Prince of Wales Island, Alaska, USA, 2009–2012. The overlaid colored shading results in the 20% quantile RSS predictions being separated into old-growth (red) and second-growth (orange) forest.

Southeast Alaska and the coastal Pacific Northwest (Bull et al. 2000, Davis et al. 2012, Immel et al. 2013), is circumstantial evidence of their importance to bears. Denning behavior in black bears has evolved to conserve metabolic resources during cold winters when food is scarce (Hellgren 1998). Food resources (e.g., ungulates, berries, salmon) used by bears in temperate rainforests can be abundant but vary in time and space (Davis et al. 2006, Hertel et al. 2018, Service et al. 2018). Human effects (e.g., hunting, development, climate change) represent additional potential stressors to bear populations that vary spatio-temporally in coastal rainforests. Retention of an adequate pool of den structures across these landscapes may function to buffer bear populations from these vagaries in their environment, though it is not entirely clear how important they are to sustaining their populations.

We predicted there would be weaker selection for older second growth because of decomposition of denning structures. We did not observe weaker selection but instead found evidence that legacy snags in second growth may have maintained viability for the roughly 50 years from the time of the advent of industrial logging until this study. Eventually these structures will decay and become unsuitable as dens. Although Parish et al. (2010) reported snags >0.5 m used by wildlife sometimes persisted >20 years, Davis et al. (2012) reported 31% of black bear dens became unusable over an 18-year period due in part to decay and logging activities. It appears that rates of both recruitment and decay control the availability of suitable large

woody structures used as dens by black bears in coastal rainforests.

Timber harvest strategies that selectively retain the large trees and snags used as dens by black bears in coastal temperate rainforests may also promote other ecological services (Lindenmayer and Laurence 2017). Such timber harvest programs may emphasize extraction of timber value from smaller but denser stands not containing as many large trees. Retaining large trees in a mosaic of logged and unlogged patches may also promote penetration of sunlight and thus berries and forbs that bears eat (Eldegard et al. 2019), though practical considerations regarding logistic feasibility and safety of logging methods that retain trees exist (Aubry et al. 2009). Although historical logging in coastal temperate rainforests has targeted large trees (Kennedy and Spies 2004, Albert and Schoen 2013), alternative harvest strategies may be sought that are economically feasible and conserve large woody structures, balancing forest management for timber, bears, and other wildlife.

MANAGEMENT IMPLICATIONS

Predictive maps we provide from this study can assist timber harvest planning. Work still needs to be done to accurately predict where the large structures that bears select for dens exist on the landscape. Bear selection for dens in second-growth forests (and persistence of suitable dens within them) suggests that bears may be selecting for specific attributes of woody structures, especially adequate size, rather than characteristics of the surrounding forest. Black bear selection for

large woody structures, and not surrounding forest attributes, is corroborated by stronger estimated selection observed for dbh of woody structures than timber volume. Retention of high-volume forests likely promotes persistence of these large trees and woody structures, but because of the loose correlation between high timber volume and tree dbh, it may be possible to also promote den site availability by retaining large trees at a finer scale. Field reconnaissance to identify and protect structures most likely to be selected as dens (i.e., >1 m dbh) or displaying evidence of bear use may mitigate the effect of timber harvest on the available pool of black bear dens in Southeast Alaska and other ecologically similar temperate rainforests.

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LITERATURE CITED

- Alaback, P. B., G. Nowacki, and S. Saunders. 2013. Natural disturbance patterns in the temperate rainforests of Southeast Alaska and adjacent British Columbia. Pages 73–88 in G. H. Orians and J. W. Schoen, editors. North Pacific temperate rainforests. University of Washington Press, Seattle, USA.
- Alaska Department of Fish and Game [ADFG]. 2002. Black bear management report of survey-inventory activities. Alaska Department of Fish and Game, Anchorage, USA. <http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/federal_aid/02_blb_17.0_man_si.pdf>. Accessed 15 Dec 2020.
- Alaska Department of Fish and Game [ADFG]. 2011. Black bear management report of survey-inventory activities. Alaska Department of Fish and Game, Anchorage, USA. <http://www.adfg.alaska.gov/static/home/library/pdfs/wildlife/mgt_rpts/11_blb.pdf>. Accessed 15 Dec 2020.
- Alaska Department of Fish and Game [ADFG]. 2020. Black bear management report and plan, Game Management Unit 2. Alaska Department of Fish and Game, Anchorage, USA. <http://www.adfg.alaska.gov/static/research/wildlife/speciesmanagementreports/pdfs/black_bear_2020_gmu_2.pdf>. Accessed 15 Dec 2020.
- Albert, D. M., and J. W. Schoen. 2013. Use of historical logging patterns to identify disproportionately logged ecosystems within temperate rainforests of Southeastern Alaska. *Conservation Biology* 27:774–784.
- Alt, G. L. 1984. Black bear cub mortality due to flooding of natal dens. *Journal of Wildlife Management* 48:1432–1434.
- Aubry, K. B., C. B. Halpern, and C. E. Peterson. 2009. Variable-retention harvests in the Pacific Northwest: a review of short-term findings from the DEMO study. *Forest Ecology and Management* 258:398–408.
- Avgar, T., S. R. Lele, J. L. Keim, and M. Boyce. 2017. Relative selection strength: quantifying effect size in habitat- and step-selection inference. *Ecology and Evolution* 7:5322–5330.
- Barry, A. M., J. C. Hagar, and J. W. Rivers. 2017. Long-term dynamics and characteristics of snags created for wildlife habitat. *Forest Ecology and Management* 403:145–151.
- Bartoń, K. 2020. MuMIn: multi-model inference. <<https://CRAN.R-project.org/package=MuMIn>>. Accessed 1 Feb 2020.
- Bose, S., T. D. Forrester, D. S. Casady, and H. U. Wittmer. 2018. Effect of activity state on habitat selection by black-tailed deer. *Journal of Wildlife Management* 82:1711–724.
- Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. *Ecological Modelling* 157:281–300.
- Bull, E. L., J. J. Akenson, and M. G. Henjum. 2000. Characteristics of black bear dens in trees and logs in northwestern Oregon. *Northwest Naturalist* 81:148–153.
- Bunnell, F. L., E. Wind, M. Boyland, and I. Houde. 2002. Diameters and heights of trees with cavities: their implications to management. Pages 717–737 in *Proceedings of the symposium on the ecology and management of dead wood in western forests*. W. F. Laudenslayer, Jr., P. J. Shea, B. E. Valentine, C. P. Weatherspoon, and T. E. Lisle, technical coordinators. USDA Forest Service General Technical Report PSW-GTR-181, Albany, California, USA.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.
- Calabrese, J. M., C. H. Fleming, and E. Gurarie. 2016. ctmm: an R package for analyzing animal relocation data as a continuous-time stochastic process. *Methods in Ecology and Evolution*. 7:1124–1132.
- Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modelling* 197:516–519.
- Caouette, J. P., and E. J. DeGayner. 2008. Broad-scale classification and mapping of tree size and density attributes in productive old-growth forests in Southeast Alaska's Tongass National Forest. *Western Journal of Applied Forestry* 23:106–112.
- Cooper, A. B. and J. J. Millsaugh. 1999. The application of discrete choice models to wildlife resource selection studies. *Ecology* 80: 566–575.
- Davis, H., A. N. Hamilton, A. S. Harestad, and R. D. Weir. 2012. Longevity and reuse of black bear dens in managed forests of coastal British Columbia. *Journal of Wildlife Management* 76:523–527.
- Davis, H., R. D. Weir, A. N. Hamilton, and J. A. Deal. 2006. Influence of phenology on site selection by female American black bears in coastal British Columbia. *Ursus* 17:41–51.
- Delheimer, M. S., K. M. Moriarty, M. A. Linnell, and B. V. Woodruff. 2019. If a tree falls in a forest: implications of forest structure persistence for the Pacific marten (*Martes caurina*). *Ecosphere* Naturalist 10(8):e02819.
- Edworthy, A. B., and K. Martin. 2013. Persistence of tree cavities used by cavity-nesting vertebrates declines in harvested forests. *Journal of Wildlife Management* 77:770–776.
- Edworthy, A. B., and K. Martin. 2014. Long-term dynamics of the characteristics of tree cavities used for nesting by vertebrates. *Forest Ecology and Management* 334:122–128.
- Eldegard, K., J. Scholten, J. N. Stokland, A. Granhus, and M. Lie. 2019. The influence of stand density on bilberry (*Vaccinium myrtillus* L.) cover depends on stand age, solar irradiation, and tree species composition. *Forest Ecology and Management* 432:582–590.
- Gaines, W. L. 2003. Black bear, *Ursus americanus*, denning chronology and den site selection in the Northeastern Cascades of Washington. *Canadian Field Naturalist* 117:626–633.
- Gerzon, M., B. Seely, and A. MacKinnon. 2011. The temporal development of old-growth structural attributes in second-growth stands: a chronosequence study in the Coastal Western Hemlock zone in British Columbia. *Canadian Journal of Forest Research* 41:1534–1546.
- Gilbert, S. L., K. J. Hundertmark, D. K. Person, M. S. Lindberg, and M. S. Boyce. 2017. Behavioral plasticity in a variable environment: snow depth and habitat interactions drive deer movement in winter. *Journal of Mammalogy* 98:246–259.
- Hagar, J. C. 2007. Wildlife species associated with non-coniferous vegetation in Pacific Northwest conifer forests: a review. *Forest Ecology and Management* 246:108–122.
- Hellgren, E. C. 1998. Physiology of hibernation in bears. *Ursus* 10:467–477.
- Hennon, P. E., and R. L. Mulvey. 2014. Managing heart rot in live trees for wildlife habitat in young-growth forests of coastal Alaska. USDA Pacific Northwest Research Station Technical Report PNW-GTR-890, Anchorage, Alaska, USA.
- Hertel, A. G., R. Bischof, O. Langval, A. Myrsterud, J. Kindberg, J. E. Swenson and A. Zedrosser. 2018. Berry production drives bottom-up effects on body mass and reproductive success in an omnivore. *Oikos* 127:197–207.
- Hertel, A. G., S. M. J. G. Steyaert, A. Zedrosser, A. Myrsterud, H. K. Lodberg-Holm, H. W. Gelink, J. Kindberg, and J. E. Swenson. 2016. Bears and berries: species-specific selective foraging on a patchily

- distributed food resource in a human-altered landscape. *Behavioral Ecology and Sociobiology* 70:831–842.
- Hijmans, R. J. 2020. Raster: geographic data analysis and modeling. <<https://CRAN.R-project.org/package=raster>>. Accessed 1 Feb 2020.
- Hosking, J. R. M. 1990. L-moments: analysis and estimation of distributions using linear combinations of order statistics. *Journal of the Royal Statistical Society B* 52:105–124.
- Immel, D., D. H. Jackson, and M. C. Boulay. 2013. Denning ecology of American black bears in the Cascade Mountains of western Oregon. *Ursus* 24:1–12.
- Johnson, C. J., S. E. Nielsen, E. H. Merrill, T. L. McDonald, and M. S. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. *Journal of Wildlife Management* 70:347–357.
- Johnson, K. G., and M. R. Pelton. 1981. Selection and availability of dens for black bears in Tennessee. *Journal of Wildlife Management* 45:111–119.
- Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. *Journal of Wildlife Management* 68:774–7789.
- Kennedy, R. S. H., and T. A. Spies. 2004. Forest cover changes in the Oregon Coast Range from 1939 to 1993. *Forest Ecology and Management* 200:129–147.
- Kirchoff, M. D., and J. W. Schoen. 1987. Forest cover and snow: implications for deer habitat in Southeast Alaska. *Journal of Wildlife Management* 51:28–33.
- Kunkel, K. E., and D. H. Pletscher. 2000. Habitat factors affecting vulnerability of moose to predation by wolves in southeastern British Columbia. *Canadian Journal of Zoology* 78:150–157.
- Lindenmayer, D. B., and W. F. Laurance. 2017. The ecology, distribution, conservation and management of large old trees. *Biological Reviews* 92:1434–1458.
- Linnell, J. D. C., J. E. Swenson, R. Andersen, and B. Barnes. 2000. How vulnerable are denning bears to disturbance? *Wildlife Society Bulletin* 28:400–413.
- Mahon, C. L., J. D. Steventon, and K. Martin. 2008. Cavity and bark nesting bird response to partial cutting in Northern conifer forests. *Forest Ecology and Management* 256:2145–2153.
- McDonald, T. L., B. F. J. Manly, R. M. Nielson, and L. V. Diller. 2006. Discrete-choice modeling in wildlife studies exemplified by northern spotted owl nighttime habitat selection. *Journal of Wildlife Management* 70:375–383.
- McGaughey, R. J. 2018. FUSION/LDV LIDAR analysis and visualization software. Version 3.80. Pacific Northwest Research Station. USDA Forest Service. <http://forsys.cfr.washington.edu/fusion/fusion_overview.html>. Accessed 1 Oct 2020.
- Morris, L. R., K. M. Proffitt, and J. K. Blackburn. 2016. Mapping resource selection functions in wildlife studies: concerns and recommendations. *Applied Geography* 76:173–183.
- Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* 16:4–21.
- Northrup, J. M., M. B. Hooten, C. R. Anderson, Jr., and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use-availability design. *Ecology* 94:1456–1463.
- Parish, R., J. A. Antos, P. K. Ott, and C. M. Di Lucca. 2010. Snag longevity of Douglas-fir, western hemlock, and western redcedar from permanent sample plots in coastal British Columbia. *Forest Ecology and Management* 259:633–640.
- Peacock, E., K. Titus, D. L. Garshelis, M. M., and M. Kuc. 2011. Mark-recapture using tetracycline and genetics reveal record-high bear density. *Journal of Wildlife Management* 75:1513–1520.
- Pigeon, K. E., S. E. Nielsen, G. B. Stenhouse, and S. D. Côté. 2014. Den selection by grizzly bears on a managed landscape. *Journal of Mammalogy* 95:559–571.
- R Core Team. 2020. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
- Reynolds, C. 2019. LiDAR-derived forest metric models for Prince of Wales Island, Alaska. The Nature Conservancy. <<https://nrsig.org/projects/oregon-blm-lidar/files/Final%20Report-%20POW%20Forest%20LiDAR%20Models.pdf>>. Accessed 1 Oct 2020.
- Sappington, J. M., K. M. Longshore, and D. B. Thompson. 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. *Journal of Wildlife Management* 71:1419–1426.
- Service, C. N., A. W. Bateman, M. S. Adams, K. A. Artelle, T. E. Reimchen, P. C. Paquet, and C. T. Darimont. 2018. Salmonid species diversity predicts salmon consumption by terrestrial wildlife. *Journal of Animal Ecology* 88:392–404.
- Shanley, C. S., S. Pyare, M. I. Goldstein, P. B. Alaback, D. M. Albert, C. M. Beier, T. J. Brinkman, R. T. Edwards, E. Hood, A. MacKinnon, et al. 2015. Climate change implications in the northern coastal temperate rainforest of North America. *Climatic Change* 130:155–170.
- Smith, M. E., J. L. Hechtel, and E. H. Follmann. 1994. Black bear denning ecology in Interior Alaska. *International Conference on Bear Research and Management* 9:513–522.
- Stevenson, S. K., M. J. Jull, and B. J. Rogers. 2006. Abundance and attributes of wildlife trees and coarse woody debris at three silvicultural systems study areas in the Interior Cedar-Hemlock Zone, British Columbia. *Forest Ecology and Management* 233:176–191.
- Therneau, T. 2021. survival: survival analysis. R package version 3.2-11, <<https://CRAN.R-project.org/package=survival>>.
- U.S. Forest Service [USFS]. 2019a. Tongass National Forest productive old growth from cover type. Southeast Alaska GIS Library. <<https://data-seakgis.opendata.arcgis.com>>. Accessed 22 Dec 2019.
- U.S. Forest Service [USFS]. 2019b. Prince of Wales landscape level analysis project, final environmental impact statement. USDA Forest Service R10-MB-833e, Juneau, Alaska, USA. <https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd601039.pdf>. Accessed 5 Dec 2019.
- U.S. Forest Service [USFS]. 2019c. Tongass National Forest roads with core attributes. Southeast Alaska GIS Library. <<https://data-seakgis.opendata.arcgis.com>>. Accessed 22 Dec 2019.
- Vanderwel, M. C., J. R. Malcolm, and S. M. Smith. 2006. An integrated model for snag and downed woody debris decay class transitions. *Forest Ecology and Management* 234:48–59.
- Welfelt, L. S., R. A. Beausoleil, and R. B. Wielgus. 2019. Factors associated with black bear density and implications for management. *Journal of Wildlife Management* 83:1527–1539.
- Western Regional Climate Center. 2019. Cooperative Climatological Data Summaries. <<https://wrcc.dri.edu/summary/Climsmak.html>>. Accessed 22 December 2019.
- Zhou, X., and M. A. Hemstrom. 2010. Timber volume and aboveground live tree biomass estimations for landscape analyses in the Pacific Northwest. USDA Forest Service General Technical Report PNW-GTR-819, Portland, Oregon, USA.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

APPENDIX A: COEFFICIENTS FROM BLACK BEAR DEN SELECTION MODELS

Table A1. Model-averaged coefficients (with 95% upper [UCL] and lower confidence limits [LCL]) for 4 discrete choice resource selection function models of black bear den selection, Prince of Wales Island, Alaska, USA, 2009–2012. Each model included a specific target covariate of management interest (target covariate) and a suite of other supporting covariates. The target covariate for each model was woody structure diameter at breast height (dbh, m), old-growth forest land cover class (categorical), second-growth age (yr), and timber volume (m^3/ha).

Covariate	Model											
	Dbh			Old growth			Second-growth age			Timber volume		
	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL
Target covariate	1.71	1.55	1.87	−1.01	−1.54	−0.48	0.17	−0.23	0.58	0.36	0.09	0.63
Elevation (m)	−0.34	−1.48	0.16	0.02	−0.35	0.47	0.06	−0.59	1.09	−0.01	−0.6	0.48
Slope (°)	1.09	0.45	1.73	0.85	0.6	1.10	0.72	0.31	1.15	0.94	0.61	1.27
Solar radiation ($\text{watt-hour}/\text{m}^2$)	0.00	−0.36	0.37	−0.03	−0.28	0.10	−0.06	−0.52	0.15	0.00	−0.25	0.21
Topographic position index	−0.32	−0.91	−0.02	−0.02	−0.24	0.11	−0.04	−0.49	0.18	−0.02	−0.30	0.15
Ruggedness	0.08	−0.13	0.57	0.03	−0.08	0.25	0.03	−0.22	0.46	0.03	−0.10	0.33
Road density (200-m radius)	−0.01	−0.69	0.63	−0.04	−0.35	0.13	−0.03	−0.38	0.16	−0.22	−1.43	0.41

Table A2. Model-averaged coefficients (with 95% upper (UCL) and lower (LCL) confidence limits) for a generalized linear regression (GLM) predictive model used to map black bear den relative selection strength on Prince of Wales Island, Alaska, USA, 2009–2012.

Covariate	β	LCL	UCL
Slope (°)	0.59	0.35	0.84
Elevation (m)	−0.05	−0.53	0.22
Ruggedness	0.03	−0.07	0.26
Unlogged areas	−1.79	−2.44	−1.14
All LiDAR ^a return counts	0.21	0.07	0.46
Canopy rumple	0.37	0.05	0.90
Elevation L-moment L4	0.26	−0.01	0.76

^a light detection and ranging.

APPENDIX B: RELATIONSHIP BETWEEN TREE DIAMETER AND MAPPED TIMBER VOLUME

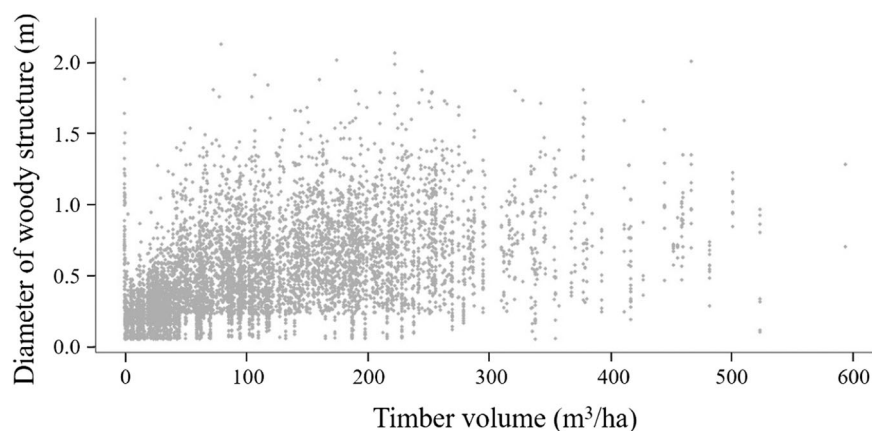


Figure B1. Scatterplot of tree diameter from forest inventory plot data versus mapped timber volume (m^3/ha) in the black bear denning study area, Prince of Wales Island, Alaska, 2009–2012.